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Scheduling Irrigation With a Neutron Probe

by

© Ross Hugh McKenzie

A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for the acceptance, a thesis entitled "Scheduling Irrigation With a Neutron Probe" submitted by Ross Hugh McKenzie in partial fulfilment of the requirements for the degree of Master of Science.

This thesis is dedicated to the memory of my father.

ABSTRACT

The neutron probe was used to schedule irrigation on 25 irrigated fields in the Lethbridge area of Alberta. Access tubes were installed in all the fields in the spring of 1980 and 1981. Moisture was measured in many of the fields once per week throughout the growing season.

The effects of soil texture and bulk density on probe calibration and soil moisture measurement for the purpose of scheduling irrigation were found to be minimal.

Two increments of moisture readings for the soil profile were used. The accuracy obtained using four readings as 25 cm depth intervals was found to be comparable to that of seven readings at 12.5 cm intervals.

The frequency of readings required was determined after examination of soil moisture changes during the growing season. For permanent crops, readings are required once per week. For annual crops readings are required once every two weeks until daily moisture use increases to between 2 and 3 mm per day.

The neutron probe was found to be a very effective tool for measuring soil moisture for the purpose of irrigation scheduling since the soil moisture status could be very quickly and accurately evaluated.

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I. INTRODUCTION

Approximately 400,000 ha of land are presently being irrigated in Alberta. A major problem facing most irrigation farmers in Alberta is knowing when to irrigate and determining how much water to apply. With the rapidly increasing equipment, energy and production costs of irrigation farming and the shortage of water in some districts, farmers have developed an increased interest in irrigation management to maximize farm production. The recent introduction of the neutron probe for the purpose of irrigation scheduling is providing this on-farm irrigation management information.

Hobbs and Krogram (1968) reported that as early as 1913, experiments were instituted to determine the consumptive use by crops in Alberta. Until the 1950's irrigation water was applied to fields by surface methods and irrigation intervals were normally scheduled on a calendar basis. Actual scheduling of irrigations was influenced by the amount of irrigation water available, topography, shape and size of the fields and the skill of the irrigator to apply the water uniformly.

In the 1950's well-designed distribution systems and precise land-levelling gave irrigators better control of water. Sprinkler irrigation became common in the 1960's. These factors lead to improved water management. Irrigators began to realize that it was important to know when to irrigate and how much water to apply. Methods used to schedule irrigation included the calendar method, the stage of crop development or the "feel" method of determining soil moisture.

In 1966, the Alberta Department of Agriculture in cooperation with the Research Branch of the Canada Department of Agriculture began offering a program called the Irrigation Gauge. The Irrigation Gauge program involved measuring the amount of soil moisture at the beginning of the growing season. Rainfall and evaporation were measured on a daily basis throughout the growing season. The evapotranspiration was calculated from evaporation data, obtained from either a Class A pan or a Gen Atmometer. By keeping a simple ledger with the initial soil moisture value at the top, evapotranspiration was entered a debit, allowing calculation of soil moisture. The difference between field capacity and the calculated soil moisture value was the soil moisture deficit or the irrigation requirement. Following irrigation, the amount of water applied was entered as a credit.

Information on consumptive use and rainfall was provided to farmers through radio and the local newspapers. Bulletin boards with weekly data also were placed near Post Offices in most of the communities. Farmers were responsible however for keeping all their own records of soil moisture. Initially, the program was well accepted by farmers. Unfortunately, the popularity of the program declined for several reasons. The primary reason was that most farmers were not prepared to take the time to keep a soil moisture budget. Farmers who did keep a record found that the calculated soil moisture information did not agree with actual soil moisture levels. This was due partly to the fact that irrigation system efficiency was not taken into account and therefore incorrect amounts

of applied irrigation water were frequently entered into ledgers, causing errors in the prediction of the next irrigation. The program, however, did serve to educate farmers that crop appearance often did not indicate a need for irrigation until after yield reduction had occurred.

In 1978, the program in the Irrigation Specialist Office in Lethbridge was modified. Instead of taking only one soil moisture sample at the beginning of the season, soil moisture samples were taken each week from each field. Calculated soil moisture levels were mailed back to the farmer along with recommendations on irrigation requirements. This method proved to be far more successful. However, there were problems with this method as well. Taking soil samples, weighing and calculating soil moisture levels, and mailing out irrigation recommendations proved very time consuming. The time delays in getting the information back to the farmer often resulted in outdated recommendations.

In 1980, in order to improve the Irrigation Gauge Program, a new Irrigation Scheduling Program was offered to irrigation farmers. The purpose of this program was to monitor soil moisture in fields on a regular basis using the neutron probe. The goal of the new program was to promote efficient use of irrigation water while attaining optimum crop yields.

The objective of this thesis is to evaluate the use of the neutron probe as a tool to schedule irrigation. Of primary importance is the establishment of an accurate calibration curve for

the neutron probe. The need for a separate calibration curve for individual soil textures and bulk densities will be evaluated. The best methods of determining field capacities and safe depletion points for scheduling irrigation with a neutron probe will also be evaluated.

II. LITERATURE REVIEW

A. Introduction

Irrigation scheduling involves determining when to irrigate and how much water to apply to a field. The purpose of irrigation scheduling is to provide water for optimum crop growth and maximum yield.

The benefits of irrigation scheduling to farmers are:

1. increased crop yields in both quantity and quality,
2. more efficient utilization of farm labor,
3. more effective use of water,
4. reduced leaching of plant nutrients, and
5. reduced drainage requirements (Stanley and Associates, 1978).

The benefits of irrigation scheduling to irrigation districts are:

1. improved forecasting, scheduling and control of irrigation water deliveries,
2. more efficient use of water conveyance and distribution systems,
3. reduced diversion and pumping requirements, and
4. reduced water demand during peak evapotranspiration periods (Stanley and Associates, 1978).

Other benefits include improved economic conditions as a result of higher yields in the irrigation region, more efficient use of land and water resources and reduced adverse environmental impact of irrigation.

Criddle and Haise (1957) stated that to operate an irrigation

farm efficiently, a farmer needs to know how much water is required to grow the crop, the amount of water that can be stored in the soil root zone, how much of that stored water can be used before reapplying water, the amount of water withdrawn by the crop at the time he irrigates and the length of time the water must be in contact with the soil to replace the amount used.

B. Concepts of Soil Moisture Status

To schedule irrigation, the amount of water a soil can hold and how much is available to plants must be determined. The characteristics of soil such as texture, structure and bulk density all have an effect on the water holding ability of soil.

1. Soil Moisture Levels

The size and distribution of soil pores and the size of soil particles play a most important role in how much water a soil can hold. Water is held to soil particles by adhesive and cohesive forces. When water enters pore spaces, displacement of air results. When all the pores of a soil are completely filled with water, the soil is considered to be saturated. Water in larger pores will move downward in a soil due to the gravitational forces. This water is referred to as "free" or "gravitational" water. After drainage has virtually ceased, the soil moisture content is referred to as "field capacity". As water evaporates or is transpired, the water content of the soil is reduced. When a plant wilts and remains in a wilted condition for a period of 24 hours or more, the soil moisture is at "permanent wilting point". The water that is held between field

capacity and wilting point is referred to as "plant available water".

Determining the allowable depletion of water for a particular crop growing on a specific soil involves the water holding capacity of the soil and volume of available moisture which can safely be withdrawn without stressing the crop.

Soils of different textures have different water holding capacities. Sandy soils have low water holding capacities while fine-textured soils have higher water holding capacities (Table 1). Varying water holding capacities of soils play a major role in development and operation of irrigation scheduling programs.

2. Problems Associated with Soil Moisture Measurements

The major problem of establishing soil moisture parameters such as field capacity and wilting point is that they are not fixed values. It is very difficult to establish exact field capacity and wilting point values. Figure 1 shows typical values of field capacity and wilting point for different soil textures.

The difficulty of estimating field capacity can be a serious problem in scheduling irrigation. One method used to estimate field capacity is to measure soil moisture several days after a saturating rain or a full irrigation. The value obtained will represent a reasonable estimate of field capacity. The accepted scientific technique of estimating field capacity is to use pressure plate apparatus (Taylor and Ashcroft, 1972). With this method, saturated soil is placed in a sealed pressure plate and 1/3 Bar equivalent suction (-33 kPa) is applied. When the outflow of soil water from

Table 1 Typical volumetric soil moisture contents (%) for several different soil textures.

SOURCE: Personal Data

TEXTURE	WILTING POINT	FIELD CAPACITY	PLANT AVAILABLE WATER
Sandy Loam	4	10	6
Loam	10	23	13
	18	37	19
Clay Loam	28	47	19

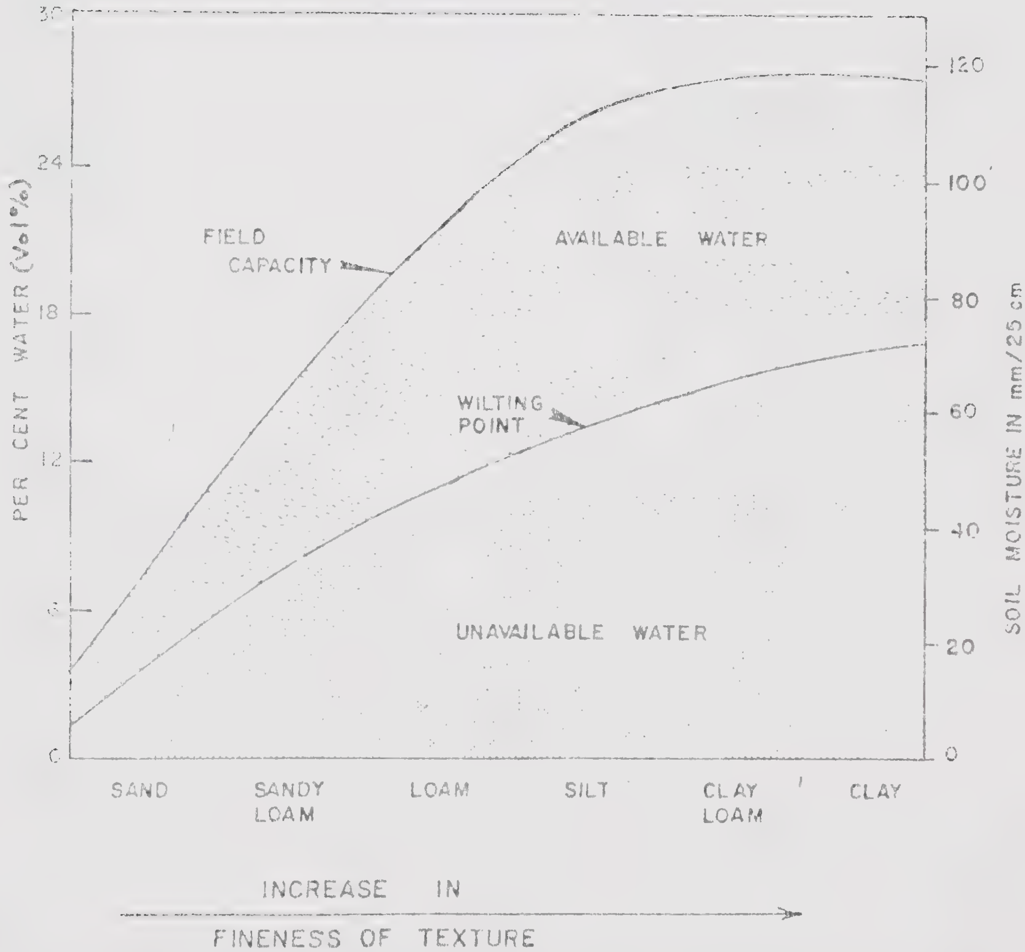


FIGURE: I RELATIONSHIP BETWEEN SOIL MOISTURE AND SOIL TEXTURE
SOURCE: BUCKMAN AND BRADY, 1972

the pressure plate ceases, the soil moisture content is considered to be approximately at field capacity.

The estimation of wilting point is not as critical as is the estimation of field capacity because in many irrigation scheduling programs, the amount of moisture depleted from the soil is determined, and that is the amount of water added to bring the soil back to field capacity. However, the advantage of having a wilting point value makes the estimation of the safe depletion point more accurate. One method used to estimate wilting point is to grow sunflowers in a given soil and when the sunflowers enter a permanent wilting condition, the soil moisture level will be at permanent wilting point. Another method of estimating permanent wilting point is by using a rule of thumb that wilting point is generally about half of the total soil moisture. The third and accepted scientific method is to use pressure plate apparatus (Taylor and Ashcroft, 1972). With this method, saturated soil is placed in a sealed pressure plate and 15 Bar equivalent suction (-1500 kPa) is applied. When the outflow of soil water from the pressure plate has ceased, the soil moisture content is considered to be approximately at wilting point.

Hysteresis is another problem which complicates soil moisture studies. Hysteresis means that values of water content at a given suction are different, depending on whether the soil is on a wetting or a drying cycle. As a result of hysteresis, the water content of a soil is greater in the drying stage than in the wetting stage at the same soil suction. However, in measuring soil moisture for the purpose of irrigation scheduling, hysteresis is rarely considered,

because it is difficult to quantify and incorporate into an irrigation scheduling program.

C. Consumptive Use

The term consumptive use is usually used synonymously with evapotranspiration. Both terms refer to the combined loss of soil moisture through evaporation from the soil and transpiration by plants.

The rate of evapotranspiration determines a plant's need for water. If rainfall is insufficient or does not occur at the proper time to meet the plant's need, plant growth will benefit from irrigation (Taylor and Ashcroft, 1972). One of the purposes of measuring consumptive use is to determine the irrigation requirements of crops. For plants to remove available water, energy must be used. The force or tension with which water is held depends on the amount of water in the soil. When soil moisture is near field capacity, little energy is required to remove the water; however, as more and more water is removed, more and more energy is required (USDA, 1964).

Taylor and Ashcroft (1972) listed three major factors which affect the rate at which plants remove water:

1. The condition of the atmosphere into which the water is transpired, including factors such as net radiation, temperature, humidity and air movement.
2. The kinds of plants and their condition, including degree of plant cover, plant shape, the stage of maturity, the number and arrangement of stomata and the opening and closing of the

stomata.

3. Soil parameters, including soil aeration, the soil-water potential, and the rate at which water can move to the plant roots.

Researchers have found that as soil moisture decreased, the ratio of actual evapotranspiration (AE) to potential evapotranspiration (PE) also decreased. Figure 2 (Baier and Robertson, 1966) shows typical relationships of available soil moisture to AE:PE ratio. Each curve represents either theoretical or actual research results. Curves A, C, G and H are theoretical while all others represent actual results. All curves on the graph with the exception of A, show that as available soil moisture decreased, the AE:PE ratio also decreases.

Therefore, when the level of available soil moisture decreases, the water remaining in the soil gradually becomes less available to plants. When crops must use large amounts of energy to take up water, yield reductions occur. For this reason, safe depletion points have been established for most agricultural crops. Safe depletion refers to the amount of available moisture which can be removed without causing significant reductions in yield. Typical safe depletion points for some crops are (USBR, 1974):

Crop	Percentage allowable depletion
Grain	60
Potatoes	50
Sugar Beets	40
Alfalfa	60

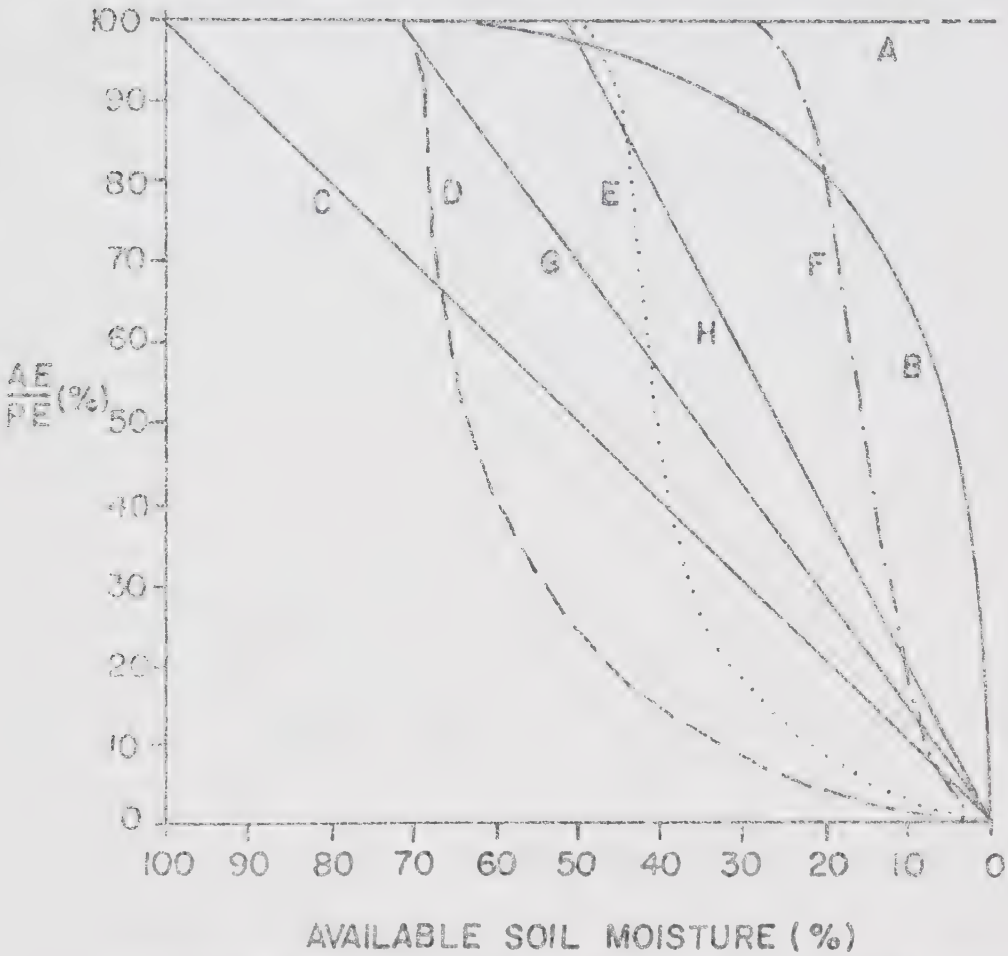


FIGURE 2 RATIO OF AE TO PE FOR VARIOUS LEVELS OF SOIL MOISTURE.

SOURCE: BAIER AND ROBERTSON (1966).

D. Method of Determining Irrigation Requirements

There are three main methods of determining irrigation requirements. One is based on determining consumptive use of crops to predict irrigation requirements using meteorological parameters. The second is based on using the plant as an indicator of water deficit while the third is the actual measurement of soil moisture to determine the need for irrigation (Haise and Hagan, 1967).

The amount of soil moisture lost by evapotranspiration is influenced by the length of the growing season, temperature, humidity, wind, sunlight, type of crop, stage of growth and the soil moisture status.

1. Meteorological Approaches

One method of estimating evapotranspiration is through a meteorological approach. Numerous formulae have been developed for calculating evapotranspiration. The three most practical methods are the Blaney-Criddle method, the Jensen and Haise method and Open-Pan evaporation.

The Blaney-Criddle method is used to determine evapotranspiration from climatological data. The procedure is to correlate existing evapotranspiration data for different crops with the monthly temperature, percent of daytime hours, and length of growing season. The correlation coefficients are then applied to determine the evapotranspiration for other areas where only climatological data are available (Schwab *et al.*, 1966). Monthly evapotranspiration is computed by:

$$u = \frac{ktp}{100} = kf$$

u = monthly evapotranspiration,

k = monthly evapotranspiration coefficient (determined for each crop from experimental data)

t = mean monthly temperature,

p = monthly percent of daytime hours of year, and

f = $\frac{(tp)}{100}$ monthly evapotranspiration factor (Schwab et al., 1966).

The Jensen and Haise method uses solar radiation to estimate evapotranspiration. The basic parameters in the equation are solar and sky radiation flux. The equation developed is an energy balance equation:

$$E = Rs(1-r) + Ra-(Rg + Rp) - A$$

E = rate of evapotranspiration,

Rs = solar and sky radiation flux,

r = reflectance or albedo,

Ra = thermal radiation flux from the atmosphere,

Rg+ Rp = thermal radiation flux from the ground and plant respectively,

A = sensible heat flux to the air (Schwab et al., 1966).

The Open Pan method involves determination of crop moisture use using evaporation data and empirical coefficients. The coefficients are determined through extensive research and vary with crop type, stage of growth and fraction of the soil surface covered by the crop. The evapotranspiration is determined by multiplying the pan evaporation by the crop coefficient factor. Open pans can be substituted by atmometers; however, atmometers require their own coefficients as

they respond to climatic changes more quickly than pans.

The advantage of using meteorological approaches to irrigation scheduling is that based on the calculated crop moisture, a prediction can be made as to when the next irrigation of a crop will be required. The disadvantage of this method of predictive irrigation scheduling is that periodic soil moisture measurements must be made to check and verify the accuracy of the predictions. Therefore the meteorological approach to irrigation scheduling must be combined with an accurate method of measuring soil moisture.

2. Plant-Water Indicators

Plant growth is directly related to the water balance in plant tissue. When a water deficit develops, physiological processes are disturbed resulting in reduced crop growth and yield. Observing or measuring water stress in plants can result in a practical guide to irrigation.

Some of the visual indicators of water stress are:

1. plant color,
2. plant movements, e.g. leaf angle and,
3. growth of an indicator plant in association with a crop.

Plant wilting is the most obvious sign of plant water stress. Most visual indicators do not warn the irrigator of a plant water deficit soon enough for timely irrigations to prevent physiological damage (Haise and Hagan, 1967).

Leaf reflectance and temperature can also be used to indicate plant water stress. A clean healthy leaf with turgid mesophyll

tissue will reflect more infrared light than leaves with flaccid cells. Leaf temperature has also been measured with an infrared thermometer. It is possible to detect differences in plant temperature as a result of soil water deficits, which aid in indicating a need for irrigation. However, care must be taken to distinguish between a soil water deficit and other factors such as plant disease. A plant will exhibit signs of stress when soil water levels are below safe depletion. However, if the plant is diseased, it may also show similar signs of stress. Soil salinity or poor soil fertility levels can also cause plant stress. Therefore, the major problem with observing plant stress for the purpose of irrigation scheduling is that stress as a result of low soil moisture levels can easily be confused with plant stress caused by a number of other factors. Another problem with this method is that it does not tell the irrigator how much water to apply to the stressed crop (Haise and Hagan, 1967).

Another method for estimating consumptive use involves measuring the plant water balance. This may involve measuring relative water content, stomatal opening, transpiration rate, or the osmotic and water potentials. The determination of relative water content should be a reliable indicator of irrigation needed due to good correlations between plant water potential and plant growth. A problem arises due to the fluctuations in plant water potential and variation with the plant part selected for measurement. This would present problems of interpretation when scheduling irrigations under variable soil and climatic conditions. The other methods (stomatal opening, transpiration rate, and the osmostic and water potentials) have not

been developed and also have practical limitations for determining irrigation need (Haise and Hagan, 1967).

3. Soil Water Indicators

Soil water indicators or methods of soil water measurement have received the greatest attention with respect to scheduling irrigation. The two basic methods of determining soil water status are by measuring either the soil water content or the soil water suction.

There are five common methods of measuring soil moisture. They are the feel method, the gravimetric method, tensiometers, electrical resistance blocks and the neutron scatter method.

a. Feel Method

The simplest method of determining soil moisture is the feel method. It involves taking a soil sample and feeling, squeezing and rolling the sample in one's hand. By determining the soil texture by feel and observing how the soil moisture sample reacts to rolling and squeezing, it is possible to estimate the amount of moisture in the soil. Table 2 gives a guide for judging amount of moisture in a soil. Using feel and appearance of the soil, an experienced person can estimate soil moisture to within 10 to 15 percent. This of course, is not a very scientific method and is not an accurate method of soil moisture determination, but does give an approximate and inexpensive estimate.

b. Gravimetric Sampling

The gravimetric method of soil moisture determination involves physically taking soil samples at specified increments from a specific

Table 2 Guide for judging amount of moisture in a soil using the feel method.

SOURCE: Alberta Agriculture, Irrigation Guide, 1974.

SOIL MOISTURE REMAINING	LOAMY SAND	SANDY LOAM	LOAM SANDY CLAY LOAM	CLAY LOAM SILTY LOAM
Field Capacity - 100%	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand. 50 mm per 30 cm 10%	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand. 70 mm per 30 cm 15%	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand. 95 mm per 30 cm 23%	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand. 115 mm per 30 cm 28%
100 to 75%	Tends to stick together slightly sometimes forms a very weak ball under pressure. 50 mm - 40 cm 10 - 8.5%	Forms a weak ball breaks easily, will not slick. 70 mm - 60 mm 15% - 13%	Forms a ball, is very pliable, slicks readily if relatively high in clay. 95 mm - 80 mm 23% - 19%	Easily ribbons out between fingers, has slick feeling. 115 mm - 100 mm 28% - 24%
75 to 50%	Appears to be dry, will not form a ball with pressure. 40 mm - 35 mm 8.5 - 7%	Tends to ball under pressure but seldom holds together. 60 mm - 50 mm 13 - 11%	Forms a ball somewhat plastic, will sometimes slick slightly with pressure. 80 mm - 70 mm 19 - 16%	Forms a ball, ribbons out between thumb and forefinger. 100 mm - 85 mm 24 - 20%
50 to 25%	Appears to be dry, will not form a ball with pressure* 35 - 25 mm 7 - 5.5%	Appears to be dry, will not form a ball* 50 mm - 40 mm 11 - 8.5%	Somewhat crumbly but holds together from pressure. 70 mm - 55 mm 16 - 13%	Somewhat pliable will ball under pressure 85 mm - 65 mm 20 - 16%
	Dry, loose, single-grained flows through fingers. 25 mm - 20 mm 5.5 - 4.5%	Dry, loose, flows through fingers. 40 mm - 30 mm 8.5 - 7.5%	Powdery, dry, sometimes slightly crusted but easily broken down into powdery condition. 55 mm - 40 mm 13 - 10%	Hard, baked, cracked, sometimes has loose crumbs on surface. 65 mm - 50 mm 16 - 12%

FEEL OR APPEARANCE OF SOIL AND MOISTURE REMAINING IN MILLIMETRES OF WATER PER 30 cm OF SOIL AND AS A DRY WEIGHT PERCENT.

*Ball is formed by squeezing a handful of soil very firmly.

location in a field. Each individual sample is placed in an air tight container and transported to a laboratory. Samples are weighed and placed in a drying oven at $105^{o}C$. When the samples have reached a stable weight, they are removed from the oven and re-weighed. Then the mass percent of water in the sample can be calculated. A major problem however is that the bulk density of the soil is required to obtain volumetric moisture content. Obtaining accurate and representative bulk density samples is very difficult. The formula for calculating volume percent moisture is:

$$\text{Vol \%} = \text{Db} \times \frac{\text{wt of water in grams}}{\text{wt of dry soil in grams}} \times 100$$

Db = bulk density of soil (g/cm^3).

The depth of moisture in the sample can be determined by multiplying the volume percent by the depth of soil sampled.

The main advantage of the gravimetric method is that it is relatively simple. To use this method for scheduling irrigation, accurate bulk density, field capacity and safe depletion values must be established. These values can be extremely difficult to establish. Other disadvantages of gravimetric sampling are that it is a destructive technique and that the same site cannot be repeatedly sampled. As well, the procedure of sampling is exhausting, requiring hard physical labor. After samples are taken, there is a time delay of 24 to 36 hours to allow drying of the samples and calculation of soil moisture content. This is a major disadvantage in scheduling irrigation because timing of irrigations is so important.

c. Tensiometers

Tensiometers are instruments which consist of a porous cup

filled with water and are placed in direct contact with the soil at a specified depth. Movement of water from the porous cup into the surrounding soil causes a negative pressure or suction in the instrument which is measured by a vacuum gauge on the tensiometer. The increase of suction of water from a tensiometer indicates that the soil is drying out.

When soil is wetted, the soil suction on the tensiometer is reduced and water moves back into the tensiometer through the porous tip. This results in lowering the negative pressure in the tensiometer and causes the vacuum gauge reading to drop toward zero. The tensiometer is sometimes referred to as a mechanical root because of the movement of water through its porous tip.

Tensiometers are accurate for measuring soil tensions from 0 to 1 Bar. However, for tensions above 1 Bar, other methods of soil moisture measurement are required. When soil tension exceeds 1 Bar, tension may break the column between the soil and the tensiometer. Then, the tensiometer will require refilling with water before further readings can be taken. In sandy soils, a major portion of the available moisture for crop use occurs at suctions between 0 and 1 Bar. However, in some medium and most fine-textured soils, a considerable amount of available water may be held at tensions greater than 1 Bar. Therefore, tensiometers are not recommended for measuring soil moisture on finer textured soils.

There are several other disadvantages of using tensiometers. One is that the presence of water in the porous cup stimulates root growth.

The rate of soil moisture extraction around the cup due to a higher root density may be greater that the surrounding soil, resulting in inaccurate readings.

A potential problem with tensiometers is that the pores of the ceramic tip may gradually become clogged with salt crystals from the soil solution. This reduces the rate that water will transfer through the tip, increasing the time required for tensiometers to respond to changes in soil moisture conditions. This problem is further aggravated in calcareous or saline soils. Since the tension readings do not give the amount of water held in the soil or amounts of water that must be applied to bring the soil back to field capacity, tensiometers do not indicate how much water to apply when irrigation is required.

d. Electrical Resistance Methods

Electrical resistance units operate on the principle that a change in moisture content produces a change in electrical properties of soil. The theory is that if conductivity units are made of a water absorbent block with two carefully spaced electrodes are permanently embedded in the block, a resistance meter can be used to measure changes of electrical resistance between the electrodes. The blocks are buried in the soil, and the electrodes are attached with wires that are exposed on the soil surface. The resistance blocks buried in the soil respond to changes in soil moisture content. The amount of moisture in the blocks determines electrical resistance; therefore, any change of resistance is an indirect measure of the change in soil moisture (USDA, 1964).

Resistance blocks are made usually with gypsum, although nylon and fibreglass have been used, either alone or in various combinations. The resistance units are usually measured with an alternate current bridge (W.M.O., 1968).

The gypsum units operate over a range of 1 to 15 Bars. Gypsum units operate best over the drier range of soil moisture. However, on wetter soils, at suctions less than one Bar the units may disintegrate because when the gypsum becomes saturated, they may gradually dissolve. The nylon and fibreglass units are more sensitive at a higher soil moisture content that gypsum units. The nylon and fibreglass units are sensitive at tensions as low as 0.1 Bar and are not subject to disintegration. The time lag for the gypsum units to respond to additions of water is about one day while the time lag for nylon and fibreglass units is shorter. The size of the blocks ranges from 4 x 3 x 0.5 cm for fibreglass to 6 x 4 x 1 cm for gypsum units (W.M.O., 1968).

Advantages of using resistance blocks include low cost, rapid speed which readings can be made and the potential for automating irrigation systems using resistance blocks.

All three types of blocks are sensitive to soluble salts, and readings will be affected by concentrations of fertilizer if a block is near a fertilizer band. Blocks are also sensitive to temperature, although this is not a major source of variation. Resistance blocks are also subject to hysteresis just as soil is.

Electrical resistance units must be calibrated for each soil type

in which they are used. This can be done in either the laboratory or field, usually on the drying curve. It is often difficult however to obtain a stable calibration curve for a large number of resistance units. This means that the method is unsuitable where quantitative results are needed for large scale routine use because undetected changes in calibration, variability amongst the units and the effect of differences in temperature, soluble salt content and hysteresis can lead to very large errors.

e. Neutron Scatter Method

Neutrons are uncharged particles with a mass which is almost the same as hydrogen nuclei. Since the nuclei of atoms carry a positive charge, a neutron must approach the nucleus of an atom much more closely than a charged particle for interaction to occur. The probability of interaction between the particles can be related to the ratio of the cross sectional area of the nucleus to the cross sectional area of the entire atom (Troxler Manual, 1980). This ratio is small and as a result the neutron is able to penetrate very large masses of high density.

The main type of collision between particles is elastic scattering, where a fast neutron strikes a nucleus and the neutron scatters. The laws of conservation of energy and momentum apply in such collisions. The result is that the neutron gives up part of its kinetic energy to a nucleus it strikes. This process is called thermalization. The amount of energy that can be transferred in each collision is dependent on the mass of the nucleus involved. Table 3 (Troxler Manual, 1980) lists the common soil elements and number of

Table 3 Common soil elements and number of collisions required to thermalize a fast neutron.

SOURCE: Troxler Manual (1980).

ELEMENT	AVERAGE COLLISIONS TO THERMALIZE A 4.5 MeV NEUTRON
Hydrogen	19.0
Boron	109.2
Carbon	120.6
Nitrogen	139.5
Oxygen	158.5
Sodium	224.9
Magnesium	237.4
Aluminum	262.8
Silicon	273.3
Phosphorus	300.8
Sulfur	311.1
Chlorine	343.3
Potassium	378.0
Calcium	387.3
Titanium	461.6
Manganese	528.5
Iron	537.2
Cadmium	1074.6
Lead	1975.5
Uranium	2268.6

collisions required to thermalize a fast neutron. For example, to thermalize, a fast neutron must collide with hydrogen 19 times, 120 times with carbon, 158 times with oxygen or 273 collisions with silicon. Hydrogen is seen to require the fewest collisions for the thermalization of fast neutrons. Therefore, a count of slow neutrons in the vicinity of a fast neutron source placed in a medium can provide a method of measuring the hydrogen content of that medium. Since water is the most significant source of hydrogen in soil, this technique can be used to measure the water content of soil.

A neutron probe contains a radioactive source of fast neutrons and a detector of slow neutrons. It is lowered down an access tube which is installed into the soil profile. The probe can be used to measure the volumetric moisture content of the soil repeatedly at the same location (Haise and Hagan, 1967). To determine the absolute moisture content of the soil, the neutron probe must be calibrated to relate slow neutron count to soil moisture content.

There are two disadvantages of using the neutron scatter method. The first is that an access tube must be installed in the field, which can interfere with farm operations. A second is that measurements of soil moisture near the soil surface can result in unreliable readings due to fast neutron escape into the atmosphere.

The neutron probe has a number of distinct advantages over other soil moisture monitoring methods. Characteristics of the probe include:

1. accurate and consistent measurements,

2. moisture changes can be monitored at the same location over time,
3. a relatively large volume of soil is measured at each reading,
4. various depths and increments of soil may be measured,
5. the soil is not disturbed after the access tube is installed, therefore, the technique is non-destructive,
6. soil moisture determination is very rapid, and
7. soil moisture determination can be given directly in volume percent.

The neutron scattering method of measuring volumetric soil moisture appears to be an accurate and rapid means of soil moisture measurement. Therefore, the neutron probe method of soil moisture measurement would be an appropriate and adaptable method of measuring soil moisture for the purpose of irrigation management.

E. Operation of the Neutron Probe

1. <u>Factors Which Affect the Neutron Probe</u>

There are a number of factors which may have an effect on the neutron probe, some more significant than others.

a. Hydrogen which is contained in the soil in forms other than in water is referred to as non-water hydrogen. The non-water hydrogen remains relatively constant. Therefore, non-water hydrogen may be ignored when soil moisture measurements are repeatedly taken at a given site to determine relative

moisture change. To determine absolute soil moisture content, calibration is required to remove the effect of the non-water hydrogen.

b. Soil mineral elements with wide cross sections such as boron, chlorine and titanium, can capture thermalized neutrons, and thus reduce neutron count. However, such elements are present in very small amounts in most soils, and therefore their effect is negligible. Other elements, such as iron and potassium, are relatively more abundant in some soils, and could affect the calibration curve. As in non-water hydrogen, when soil moisture measurements are repeatedly taken, relative moisture change can be determined without establishing a field calibration curve. However, to determine absolute soil moisture content, calibration is required to remove the effect of these mineral elements.

c. Soil texture is considered to have a significant effect on neutron moisture measurements (Lal, 1974). Other researchers, such as Gardner and Kirkham (1952) and Luebs _et al_. (1968) found separate calibration curves for different soil textures unnecessary. However, separate calibration curves are generally not practical or economical, except perhaps in some research situations.

d. Researchers, such as Luebs _et al_. (1968) and Lal (1974) agreed that bulk density affects neutron probe readings. They noted that an increase in bulk density results in an

increased count rate. Most soils do not have changes of more than 0.2 g/cc in bulk density and therefore significant changes in soil moisture readings due to bulk density would not result. If there are drastic bulk density changes in soils being monitored, separate calibration curves should be prepared, and checked for significant differences.

e. Dickey and Ferguson (1964) and Hanks and Bowers (1960) concluded that neutron access tubes do not have an effect on either soil temperature or soil moisture content distribution.

f. Gravel concentration had a slight effect on neutron thermalization (Lal, 1979). However, Lal did not demonstrate that gravel concentrations have a significant effect on absolute soil moisture determination with the neutron probe. Gravel concentrations of up to 60% were present at Lal's research site. This high gravel content is not characteristic of most agricultural soils.

g. The presence of abrupt moisture changes in soil will not result in errors of soil moisture measurement, provided the increment of readings is kept at 15 cm or less. Errors of individual readings from either side of the interface compensate for each other.

h. Some water in the soil is held very tightly and is referred to as bound water. Babalola (1972) found considerable amounts of water still in the soil after oven drying at 105°C. He suggests that soils be oven dried at 600°C to remove all water

from the soil, including the bound water. If there is as much bound water as Babalola states, then in order to properly calibrate a neutron probe to determine absolute moisture content, soil samples must be dried to 600^{0}C to remove all soil moisture. Further study of this theory is necessary for verification.

i. Neutron escape occurs when probe readings are taken near the soil surface. The depth from which escape will occur depends on the soil moisture content. When volumetric soil moisture content is 10% or less, neutron escape will occur when readings are taken within 24 cm of the soil surface. However, if the soil moisture content is 50%, neutron escape will occur only when readings are taken within 14 cm of the soil surface (Hanna and Siam, 1980). This escape can be prevented by placing an aluminum mesh tray, filled with soil representative of the surface soil, over the site. This prevents neutron escape when taking readings near the soil surface and thus greatly increases the accuracy of these measurements.

j. Aluminum is the best material for use as access tubes with the neutron probe as it has the least effect on neutron readings. Steel and plastic have been used as material for access tubes but both have an effect on neutron readings and require calibration of the neutron probe if used.

2. <u>Time and Accuracy of Measurements</u>

The accuracy of measurements taken with the neutron probe can be

improved by accumulating and averaging multiple measurements (Troxler Manual, 1980). The deviation of measurements is reduced by a factor of two for four measurements, three for nine measurements, four for sixteen measurements and so on. However, time used in making measurements increases geometrically while accuracy in measurement increases arithmetically. Thus, it is usually not economical to take more than four measurements. Four minute counts are used for calibration and field determination of the standard count, while one minute counts are equally the most economical in terms of time and accuracy for routine field moisture measurements.

3. Radius of Measurement of the Neutron Moisture Probe

The radius of measurement of a neutron probe refers to the distance a fast neutron will travel from the radioactive source into the surrounding soil before being slowed down. The radius of measurement is a function of the soil moisture content. As the soil moisture increases, the radius of measurement decreases. The equation in the Troxler Manual (1980) for determination of the radius of measurement is:

$$\text{Radius (mm)} = 280 - 0.27 \times (\text{Moisture content in Vol \%} \times 10)$$

The equation is valid over a range of moistures from 0 to 64% by volume and it suggests that neutron escape will not occur if soil moisture is above 10%, at a depth of 25 cm.

4. Calibration of the Neutron Probe

a. Introduction to Calibration

Calibration of a neutron moisture meter is a process

by which a curve relating the count rate in counts per minute to the volumetric moisture content of water in the soil (Holmes, 1966). The volumetric moisture content is checked using bulk density and gravimetric moisture content. Holmes stated the characteristics of the calibration curve depend on the geometry of source and detector, the materials of construction of the probe and the size and composition of the access tube.

The calibration of the neutron moisture probe can be done in either the laboratory or the field. Controlled laboratory studies are considered to be the best for calibration (Stolzy and Cahoon, 1957).

The next three sections of this paper will discuss the calibration of the probe by the manufacturers and by researchers in the laboratory and in the field.

b. Factory Calibration

Each neutron probe is provided with its own calibration curve from the manufacturer. One method of factory calibration is based on free water in pure sand and is a graph of count rate versus actual volumetric moisture content. The factory calibration involves measuring only two points on the graph, one in dry sand and the other in saturated sand. Two drums, each with an access tube installed are filled with kiln dried spherical grained sand. One of the drums is saturated with water. Measurements with the neutron probe are

then taken in both drums.

The two measured counts obtained provide the factory calibration curve. Since sand is used, there is no bound-water hydrogen or non-water hydrogen present in the drums. Therefore, the calibration curve is essentially a free water curve. However, this curve is undoubtedly not representative of most agricultural soils, as these soils contain bound water in the interlayers of clay and non-water hydrogen in both organic and mineral forms.

A second method of factory calibration involves using a set of standards made from laminated sheets of plastic which contain hydrogen, and a non-absorber of thermal neutrons. The standards are manufactured to control the ratio of plastic and the non-absorber accurately. The standards range from zero moisture equivalent to over 100% moisture equivalent. The method consists of calibrating the probe against the percent of plastic and then taking a measurement in pure water to determine the equivalent water content of the standards. At this point, the calibration is checked against dry and saturated sands to verify the results.

c. Laboratory Calibration

The accepted and most common laboratory method of calibrating a neutron probe involves filling cylindrical containers of equal height and weight with screened, homogeneous soil at different moisture contents. The soils

are packed to a uniform and consistent bulk density and an access tube is installed in each cylinder. Then, measurements are taken at specific depths with the probe. Gravimetric soil samples are also taken from the corresponding depths. As many as 4 or 6 gravimetric samples can be taken for each depth. The moisture content is then determined for the samples. With this information, a calibration curve can then be prepared. This procedure is repeated using soils of various textures to allow comparison of calibration curves for the different soils.

Another method of laboratory calibration is using neutron absorbers dissolved in solution. Neutron absorbers such as Li, B, Cl, Cd, Fe or Hg can be dissolved in solution and neutron count rates can be obtained by immersing the probe into a tube in the solution. Van Bavel et al. (1954) prepared response curves for H_3BO_3 and $CdCl_2$. Using the calibration curves for soils calibrated in the laboratory, van Bavel translated a relation between H_3BO_3, and $CdCl_2$ compound concentrations and soil moisture content. Calibration can be attempted by this method; however, it can only be done by reference to accurate soil calibration with a neutron probe of the same design. The advantages of this method are savings in labor, time and space. A normal laboratory calibration requires homogeneous soil and a considerable amount of time and labor in preparation. In this method, $CdCl_2$ is recommended, as it has the widest range of correlation to

soil moisture contents.

d. Field Calibration

A review of the literature showed that the general concern of all researchers is that a factory calibration curve must be checked before a probe is put into use to determine absolute moisture contents.

The specific methods of field calibration are as varied as are the methods of laboratory calibration. The general method of calibration is to install either one or a number of access tubes at each site. Babalola (1978) installed tensiometers at depths of 7.5, 30, 60, 90, 120 and 150 cm at a distance of 50 cm from the access tubes. Gravimetric soil moisture samples were generally taken at two to three locations around the access tube, and half-minute neutron probe readings were taken at depths of 10, 20, 30, 60, 90, 120, 150 and 180 cm. Gravimetric soil samples were taken from the 0 - 15 cm layer and subsequently at 30 cm depth intervals down to 195 cm at two locations near the access tube.

Rawls and Asmussen (1973) took one minute neutron probe readings at 6 inch intervals to a depth of 36 inches. Gravimetric soil samples were taken at 3 inch increments to a depth of 42 inches at two locations near the access tube.

Luebs et al. (1968) took one minute neutron probe probe readings at depths of 7.5, 22.5, 37.5, 52.5, 67.5 and 82.5 cm. Gravimetric soil samples were taken at six

locations around the access tube at 15 cm increments.

Research results by Rawls and Asmussen (1973) and Babalola (1978) showed only one field derived calibration curve for soils of contrasting physical properties. Babalola (1978) used loamy sand, sandy loam, sandy clay loam, and clay loam soils for calibration of the neutron probe. Luebs et al. (1968) used a loamy sand, three sandy loam soils and a clay soil for neutron probe calibration. Rawls and Asmussen (1973) used eleven different soil series ranging in texture from a loamy sand to a sandy clay loam.

Babalola (1978) and Rawls and Asmussen (1973) both derived a linear curve, developed using least squares, relating the ratio of neutron probe counts per standard counts to volumetric soil moisture values. Rawls and Asmussen (1973) found their fitting to give a correlation coefficient of 0.92 and a standard error of 3.2%. Babalola (1978) found a correlation coefficient of 0.89 with a standard error of 0.17. The calibration curve prepared by Rawls and Asmussen (1973) is shown in Figure 3, and the curve prepared by Babalola (1978) is shown in Figure 4. In both cases, the factory calibration curve was unacceptable for measuring absolute soil moisture in the field when gravimetric moisture content obtained in the field was compared with that estimated from the factory calibration.

Rawls and Asmussen (1973) found their field determined

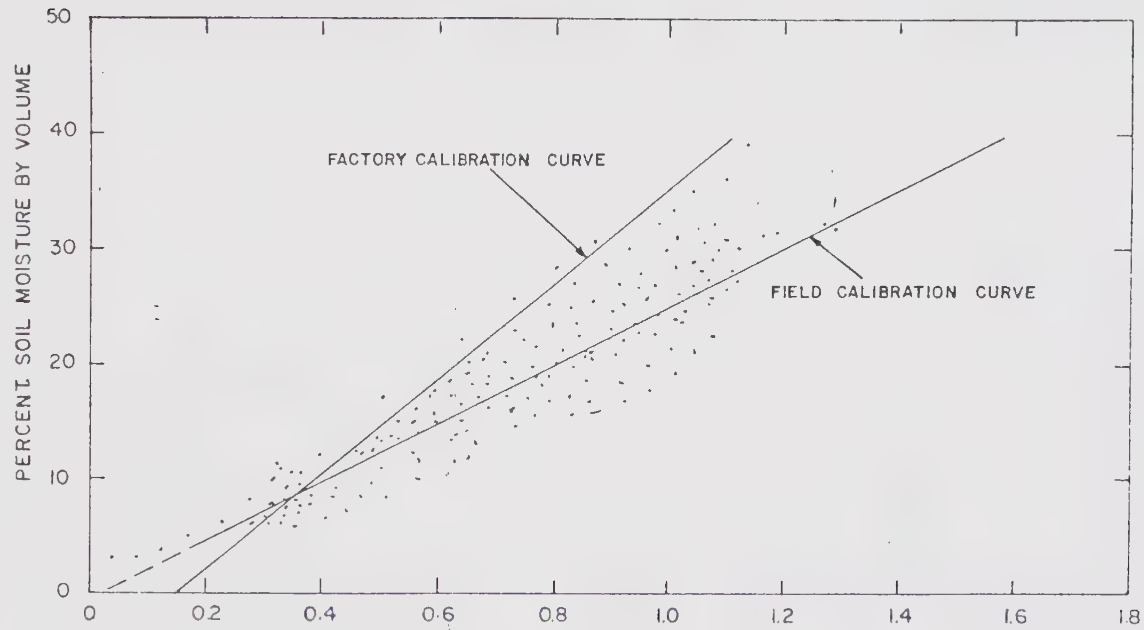


FIGURE NO. 3

MOISTURE CONTENT VERSUS COUNT RATIO FOR ALL SOILS AT ALL DEPTHS IN THE FIELD.

SOURCE: RAWLS AND ASMUSSEN (1973).

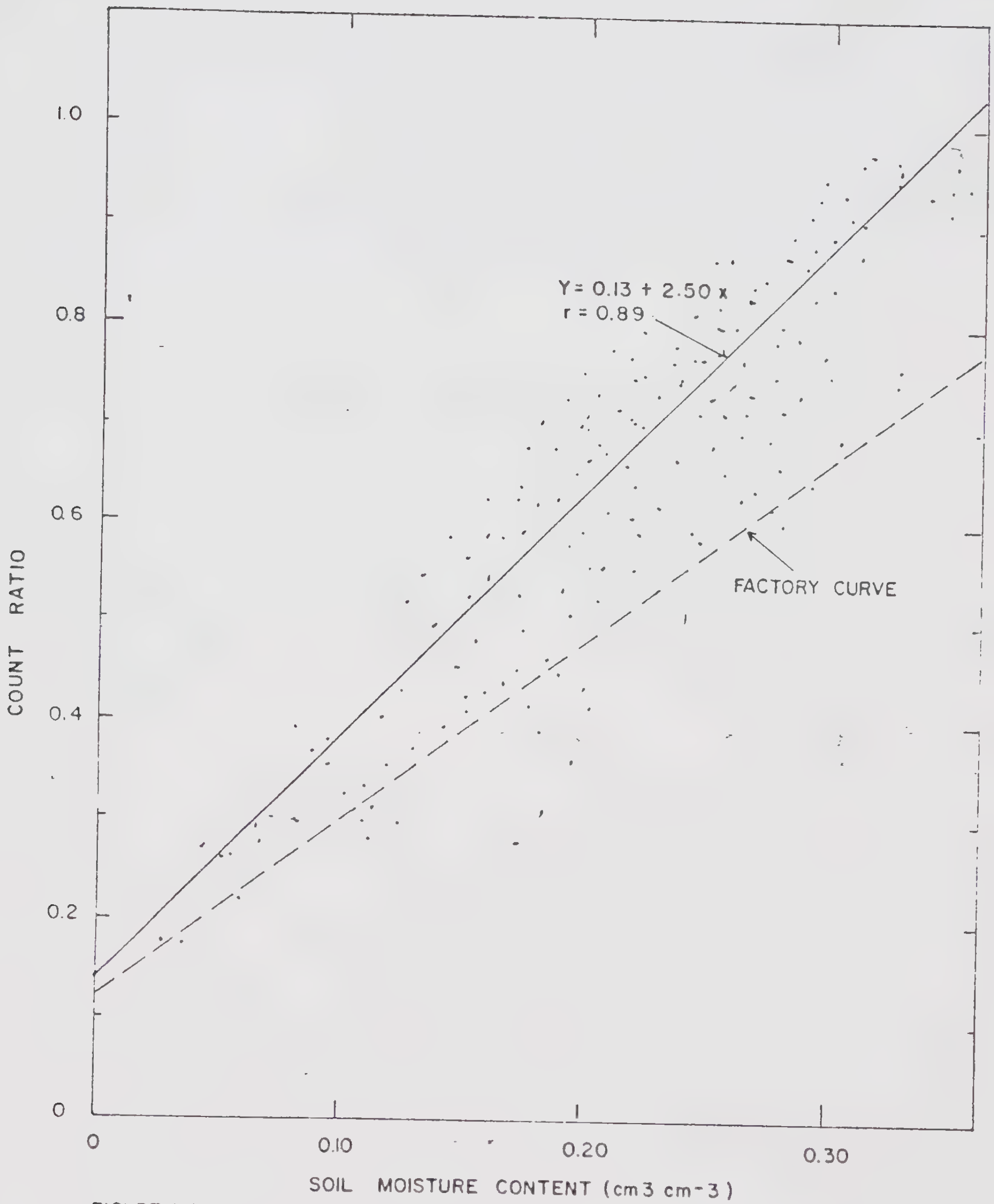


FIGURE NO. 4 COUNT RATIO VERSUS SOIL MOISTURE CONTENT FOR ALL SOILS AND DEPTHS ON THE FIELD.

SOURCE: BABALOLA (1978)

calibration curve to be independent of soil depth and soil texture. Their conclusion was that one calibration curve is satisfactory for all soils at all depths.

Babalola (1978) also found that it was possible to establish one calibration curve for all soils and depths. However, he cautioned that absolute moisture content may not be very accurate as the standard error of estimates ranged between 2.3 and 6.8 percent.

e. Conclusions on Neutron Probe Calibration

Factory calibration curves have been shown to be inadequate for measuring absolute moisture content. If absolute moisture content is to be determined with a neutron probe, either laboratory or field calibration becomes necessary.

Burn (1964) suggests that laboratory calibration is more stable and reliable than field calibration due to controlled conditions. The claim is that field calibration is inadequate for maximum accuracy due to heterogeneity of moisture content. Some researchers such as Burn (1964) believe that controlled laboratory conditions will result in homogeneity of moisture content, therefore, resulting in a more accurate calibration curve for a neutron probe. However, laboratory calibration curves still must be checked and verified in the field.

There seems to be no consensus as to the reliability of using a single calibration curve for all soils (Babalola, 1978).

Some researchers (Gardner and Kirkham, 1952; Rawls and Asmussen, 1973; Babalola, 1978) suggest that a single calibration curve can be used. A number of other researchers (Luebs *et al.*, 1968; Lal, 1974) claim that different soils require their own calibration curves due to the influence of varying soil properties such as soil texture, bulk density, stratified soil moisture layers, gravel in soil and soil mineral elements.

Calibration of the neutron probe is required to remove the effects of soil mineral elements and non-water hydrogen when determining absolute soil water content. Normally, only one calibration curve is required unless there are vast differences in soil properties such as soil mineral element content.

III. MATERIALS AND METHODS

A. Site Descriptions

1. Location

Twenty-seven sites were initially chosen for extensive study of the use of the neutron probe for on-farm irrigation scheduling in 1980. All sites were in either the Lethbridge Northern Irrigation District or in the St. Mary River Irrigation District. Table 4 gives the farmer cooperator, legal land description, soil texture, type of crop grown and type of sprinkler irrigation system used for each monitoring site. Several sites were monitored in only one of the two seasons for various reasons.

2. Topography

The topography of the sites monitored were generally level to undulating. The sites were all chosen based on the visual uniformity of both soil and topography.

3. Surfical Geology

The soils at most of the sites consist of lacustrine or fluvial lacustine materials. These materials are underlain by glacial till material. Depths to the till layer are variable but range from 0.5 to 2.0 m. Only the site at Lakeside Colony has glacial till material to the surface.

B. Installation of Equipment

Each neutron probe monitoring site was chosen with the cooperating farmer involved. At each site, an aluminum access tube 120 cm in length and 5 cm in diameter with a metal cap on the bottom end was

Table 4 Farmer co-operators, legal land locations, and soil textures of all sites. The crops grown in 1980 and 1981 and the type of irrigation system are also shown.

NAME	LOCATION	TEXTURE	1980	1981	SYSTEM
J. Machielse	NE 35-8-20-W4	CL	Sugar Beets	Soft Wheat	Wheelmove
J. Machielse	NE 35-8-20-W4	CL	Peas	Sugar Beets	Wheelmove
J. Machielse	NE 35-8-20-W4	CL	Soft Wheat	Barley	Wheelmove
J. Machielse	SW 25-8-20-W4	CL	Soft Wheat	Barley	Wheelmove
J. Machielse	SW 25-8-20-W4	CL	Sugar Beets	Soft Wheat	Wheelmove
J. Machielse	SW 25-8-20-W4	CL	Oats	Sugar Beets	Wheelmove
J. Machielse	NW 21-8-20-W4	SCL	Barley	Barley	Wheelmove
J. Machielse	NW 21-8-20-W4	SCL	Alfalfa	Alfalfa	Wheelmove
J. Machielse	NW 21-8-20-W4	SCL	Barley	Peas	Wheelmove
M. Perich	NW 31-10-20-W4	C	Soft Wheat	-	Wheelmove
M. Perich	NW 21-10-20-W4	C	Sugar Beets	-	Wheelmove
V. Nemecek	NE 31-10-20-W4	C	Sugar Beets	Sugar Beets	Wheelmove
V. Nemecek	NW 32-10-20-W4	C	Soft Wheat	Hard Wheat	Pivot
V. Nemecek	SW 32-10-20-W4	SCL	Hard Wheat	Barley	Pivot
S. Freyman	SE 13-10-21-W4	SCL	Corn	Corn	Pivot
S. Freyman	SW 13-10-21-W4	SCL	Corn	Corn	Pivot
C. Uytdewilligen	SW 22-10-20-W4	SCL	Soft Wheat	Soft Wheat	Wheelmove
C. Uytdewilligen	SW 22-10-20-W4	SCL	-	Sugar Beets	Wheelmove
C. Uytdewilligen	NW 15-10-20-W4	SCL	Alfalfa	Alfalfa	Wheelmove
Lakeside Colony	SW 23-8-18-W4	CL	Soft Wheat	Soft Wheat	Wheelmove
H. Lohues	SW 13-10-19-W4	CL	Sugar Beets	Soft Wheat	Pivot
H. Lohues	SE 24-10-19-W4	SCL	Sugar Beets	Barley	Wheelmove
H. Lohues	SW 24-10-19-W4	SCL	Sugar Beets	Sugar Beets	Wheelmove
H. Lohues	NW 13-10-19-W4	CL	Soft Wheat	Soft Wheat	Pivot
H. Lohues	NE 13-10-19-W4	CL	Soft Wheat	Sugar Beets	Wheelmove
H. Lohues	SW 13-10-19-W4	CL	Barley	Barley	Pivot
H. Lohues	SE 24-10-19-W4	SCL	Barley	Sugar Beets	Wheelmove
H. Lohues	SE 24-10-19-W4	SCL	Alfalfa	-	Wheelmove
H. Lohues	SE 24-10-19-W4	SCL	-	Soft Wheat	Wheelmove

installed. All the tubes were installed after seeding of the fields were completed. Most of the tubes were installed with a Giddings drill by removing a soil core 5 cm in diameter and approximately 115 cm long. Then, the aluminum access tube was pushed into the hole either by hand or with the Giddings drill. Normally about 5 cm of tube protruded above ground. Soil was also packed tightly around the access tube to prevent water from infiltrating into the soil along side the access tube. A rubber stopper was placed in the top of the access tube to prevent water from getting into the access tube.

Normally, only one tube was installed per field, with the exception of those at S. Freyman and J. Machielse. In 1980, at S. Freyman's 3 tubes were installed at legal location SW 13-10-21-W4 and 2 tubes installed in legal location SE 13-10-21-W4, and in 1981 there were 4 tubes and 1 tube installed respectively in each field. In three of J. Machielse's fields, there were 2 tubes installed approximately one metre apart in 1980 only. Rain guages were installed at all of the sites at S. Freyman in 1981.

C. Instrumentation and Sampling Procedures

All sites were monitored with the neutron probe on a weekly basis. Monitoring began in mid May and continued until just before harvest for annual crops and until mid September for perennial crops. Gravimetric soil samples were taken a minimum of three times and a maximum of four times at each site for the purpose of calibration. An effort was made to take soil moisture samples when soil moisture levels were at extremes. Unfortunately, obtaining samples at low

moisture levels was difficult, as most farmers followed the irrigation scheduling recommendations. As a result, soil moisture levels in most fields were maintained at relatively high levels.

Neutron probe readings were taken at depths of 25, 50, 75, and 100 cm. All soil moisture samples were taken at corresponding depths.

Soil samples were taken at each site in 1980 for mechanical analysis. Bulk density soil samples were taken with a B-30 drill from all fields in the spring of 1981.

D. Cropping and Irrigation of the Sites

A list of the crops grown in 1980 and 1981 as well as the types of irrigation systems used are shown in Table 4. Rainfall for the months of April to September for 1980 and 1981 are shown in Table 5. Normally, all farmers followed the irrigation scheduling recommendations as they had irrigation systems capable of keeping up with crop moisture use.

E. Delivery of Information to Farmers

Results of soil moisture testing with the neutron probe were delivered to each farmer immediately after soil testing was completed. The information and irrigation recommendations were delivered to each farmer on a card, an example of which is shown in Figure 5.

Table 5 Rainfall received at the Lethbridge Research Station from April to September in 1980 and 1981.

SOURCE: Verbal communication with H. Hobbs.

	1980	1981	LONG TERM AVERAGE (80 YEARS)
April	36.3 mm	10.4 mm	32.7 mm
May	100.6 mm	128.6 mm	55.9 mm
June	33.8 mm	102.8 mm	74.2 mm
July	31.2 mm	30.0 mm	41.6 mm
August	69.2 mm	35.3 mm	41.4 mm
September	32.1 mm	7.3 mm	40.0 mm
TOTAL	303.2 mm	314.4 mm	285.8 mm

IRRIGATION SCHEDULING

Farmer: ________________ Date: ____________

Field: ________________ Crop: ____________

Soil Moisture Information

DEPTH (cm)	FIELD CAPACITY mm.	SAFE MOISTURE DEPLETION mm.	PRESENT MOISTURE mm.	ACTUAL MOISTURE DEPLETION mm.
10–35				
35–60				
60–85				
85–110				
TOTAL				

In a __________ cm. Root Zone:

The PRESENT MOISTURE DEPLETION is ________ mm.

The SAFE MOISTURE DEPLETION is ________ mm.

Available Moisture Remaining is ________ mm.

Daily Crop Moisture Use is ________ mm.

Irrigation Recommendations:

____

____

____

____

____

For Further Information Contact:
Irrigation Specialist Office
Lethbridge, Alta. Phone 329-5137

Alberta
AGRICULTURE

FIG.5 IRRIGATION SCHEDULING CARD DELIVERED TO FARMER

IV. RESULTS AND DISCUSSION

A. Calibration of the Neutron Probe

Of fundamental importance in measuring soil moisture with a neutron probe is the procedure of calibration. The method of field calibration as described in Chapter II was used to calibrate the neutron probe. The neutron probe data was recorded in the field in the form of a count ratio. Moisture contents of the gravimetric samples were multiplied by the measured bulk density to obtain moisture content in volume percent.

To establish the calibration curve to predict soil moisture content, the neutron probe count ratio is represented as the X value and the soil moisture content in volume percent is represented as the Y value in the linear regression equation:

$$Y = a + b(X) \text{ where}$$

Slope b is: $$b = \frac{\Sigma XY - \frac{\Sigma X \Sigma Y}{n}}{\Sigma (X)^2 - \frac{(\Sigma X)^2}{n}}$$

Intercept a is: $a = (\overline{Y} - b\overline{X})$

$\overline{X}$ = mean of X

$\overline{Y}$ = mean of Y

n = number of pairs of data

Table 6 lists the calculated equations and correlation coefficients for each equation.

The calibration curve derived using all the field data is shown in Figure 6.

1. Effects of Soil Texture

To determine if soil texture had an effect on neutron probe

Table 6 Equations and correlation coefficients for all data, textures, bulk densities, and farms.

DATA USED	EQUATION	CORRELATION COEFFICIENT	NO. OF VALUES
All-Data	Y=-0.031 + 43.719 (x)	.832	320
Fine-Textured Soils	Y= 0.185 + 43.431 (x)	.817	191
Course-Textured Soils	Y= 0.069 + 43.730 (x)	.751	118
Soils with Bulk Densities of:			
1.31 - 1.35 g/cc	Y= 3.076 + 37.144 (x)	.891	42
1.36 - 1.40 g/cc	Y= 0.981 + 41.911 (x)	.693	29
1.41 - 1.45 g/cc	Y= 0.078 + 44.287 (x)	.873	100
1.46 - 1.50 g/cc	Y=-0.633 + 44.940 (x)	.794	98
1.51 - 1.55 g/cc	Y=-1.173 + 45.474 (x)	.847	51
FARMS			
Freyman	Y=3.489 + 37.472 (x)	.564	40
Uytdewilligen	Y=3.151 + 37.916 (x)	.836	40
Nemicek	Y=1.383 + 44.202 (x)	.839	36
Machielse	Y=-2.254 + 46.302 (x)	.888	92
Lohues	Y=0.860 + 42.442 (x)	.765	112

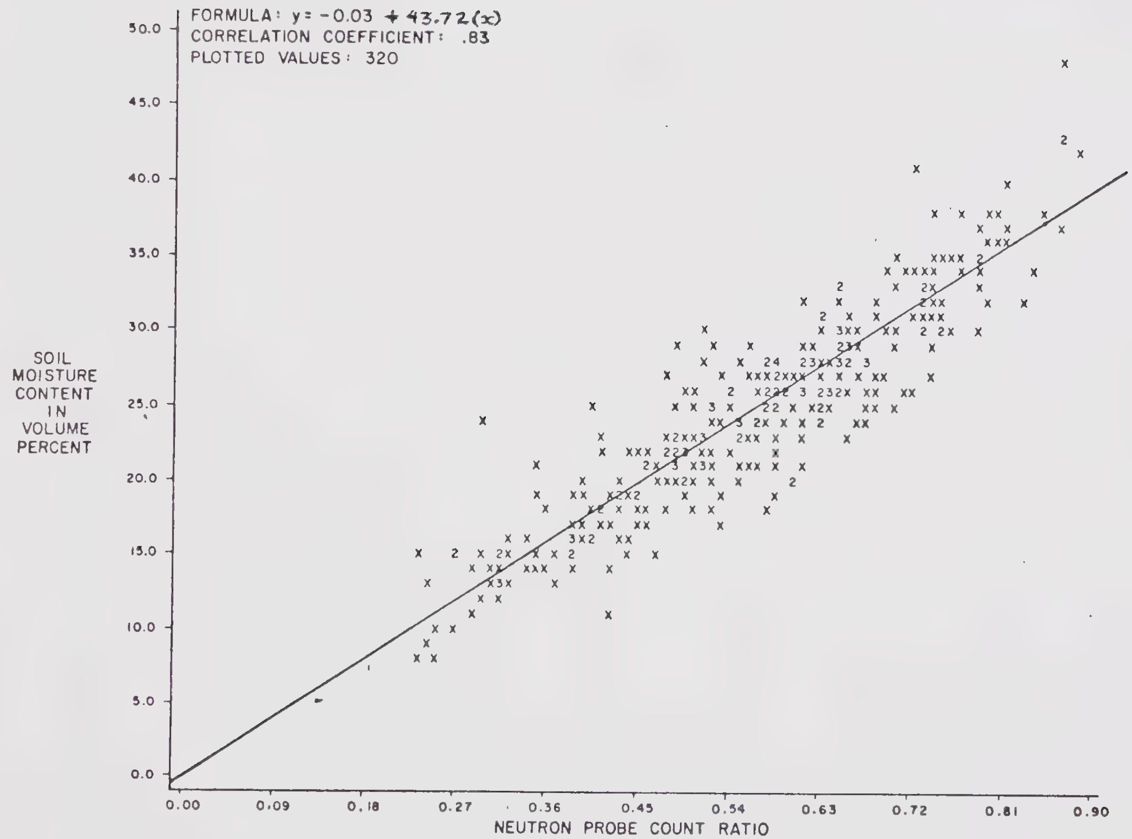


FIGURE: 6 SCATTERGRAM FOR ALL DATA

calibration, the data was split into two groups: fine-textured soils and coarse-textured soils. The soil textures that were considered to be fine-textured were: clay, clay loam, silty clay, silty clay loam and silt loam. The soils considered to be coarse-textured were sandy loam and loamy sand.

Very little difference was found between the equation obtained for the fine-textured soils and that for the coarse-textured soils. The difference in the intercepts in the calculated equations is 0.25 and the difference between the slopes is 0.30. This would result in a difference of less than one mm of water per 25 cm of soil between the two curves in measuring soil moisture.

Using the multiple regression test to compare the intercepts and the slopes of the fine and coarse textured equations, no significant difference between the intercepts and between the slopes was found.

Therefore, the null hypothesis that there is no significant difference between the calibration of the neutron probe equations for fine-textured soils and for coarse-textured soils is accepted. This conclusion is in agreement with Lal (1974) who suggested that soil texture does not have a significant effect on neutron probe calibration.

2. Effect of Bulk Density

Five calibration curves were prepared for different ranges of bulk densities. These ranges were:

1. 1.31 to 1.35 g/cc,
2. 1.36 to 1.40 g/cc,
3. 1.41 to 1.45 g/cc,

4. 1.46 to 1.50 g/cc, and
5. 1.51 to 1.55 g/cc.

These ranges allowed splitting the data for comparison of five different ranges of soil bulk density.

When comparing equations for the five bulk density ranges, shown in Table 6, two trends become apparent. The first is that as bulk density increases, the intercept of each equation decreases. The second is that as bulk density increases, the slope of calibration line increases.

Comparison of the five calibration curves and the calculated formula shows that there is a difference between each of the five calibration curves. The null hypothesis that bulk density has no effect on neutron probe calibration must be rejected with the conclusion that bulk density does indeed have an effect on neutron probe calibration.

For the purpose of measuring soil moisture for irrigation scheduling, however, the influence of bulk density is not considered to significantly affect soil moisture determinations. The all-data calibration curve represents an average of all the bulk densities. The all-data calibration curve predicts soil moisture to within 0.5 percent by volume, compared to the appropriate bulk density derived curve when the probe count ratio is between 0.40 and 0.60. If converted to mm/25 cm, the all data calibration curve would have a maximum error of 2 mm/25 cm, or a 2% error. Using the all data calibration curve, it appears there is a tendency to slightly

over-estimate soil moisture at the lower bulk density levels and slightly under-estimate soil moisture at the higher bulk denisty levels.

There are two compensating factors however. The first is that bulk density generally increases with depth. Therefore, the slight over-estimation of moisture at the shallower depths and the under-estimation at the deeper depths would likely compensate for each other to reduce the error. Second, field capacity for each depth at each site is initially determined with the neutron probe using the all data calibration curve. To calculate soil moisture deficit, the most recent probe reading is subtracted from the field capacity reading. If both readings are in error by the same percentage, the error in estimating soil moisture is eliminated.

Therefore, based on these two compensating factors, the effects of bulk density on the all data calibration curve can be ignored for the purpose of measuring soil moisture for irrigation scheduling.

3. Farm Calibration Curves

Individual farm calibration curves were also examined. It is conceivable that in the future, individual farms or several adjacent farms may utilize a neutron probe strictly to schedule irrigation on their own farms. Therefore a calibration curve was prepared for each of the five farms for comparison. The correlation coefficients of four of the farms were high. The fifth farm, identified by the name Freyman, had a poorer correlation but was still statistically significant. This was likely due to a reduced range of the data values.

When comparing equations of the five farms (curves shown in Figure 7) one can see that there is a difference between some of the calibration curves.

The all data calibration curve represents an average of all the farmer calibration curves. The all data calibration curve predicts soil moisture to within 3 mm/25 cm through most of the range of data values, with the exception of the Nemecek curve which is within 4 mm/25 cm.

As with bulk density, there is one major compensating factor. Field capacity for each depth at each site on each farm is initially determined with the neutron probe using the all data calibration curve. To calculate soil moisture deficit, the most recent probe reading is subtracted from the field capacity reading. If both readings are in error by the same percentage, the error in estimating soil moisture is eliminated.

Therefore, there is little justification for separate calibration curves for individual sites or farms for the purpose of measuring soil moisture for irrigation scheduling.

4. <u>Comparison of All Data Calibration to the Manufacturer's Calibration Curve</u>

Comparison of the all data calibration curve to the manufacturer's curve shows considerable differences. The two curves are shown in Figure 8. The difference might be expected, as the manufacturer's curve is prepared by taking readings in pure sand, which contains no hydrogen in the minerals. The all data curve is prepared after taking numerous readings in soils which contains hydrogen in the

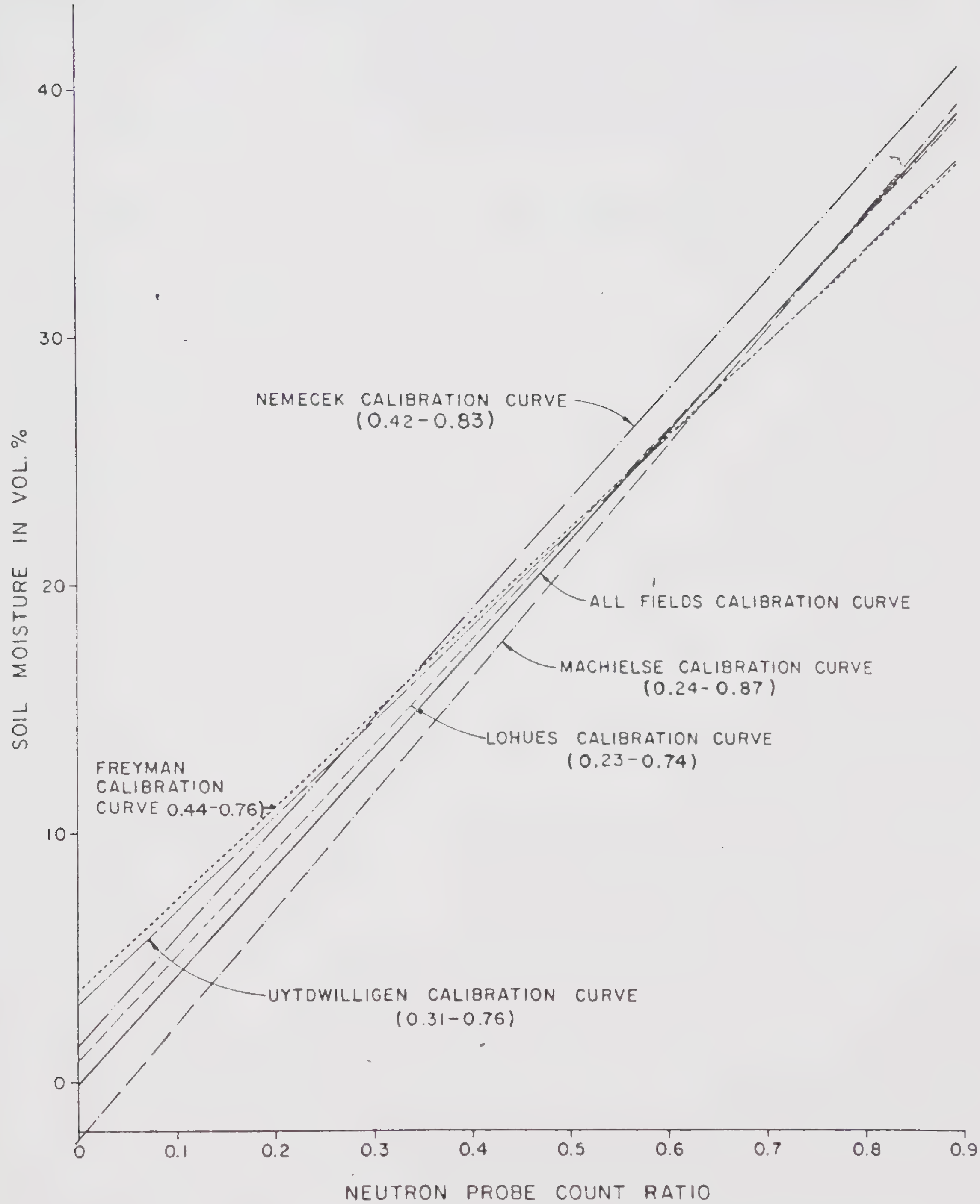


FIGURE: 7 COMPARISION OF FARM CALIBRATION CURVES

BRACKETED NUMBERS INDICATE RANGE OF DATA IN COUNT RATIO

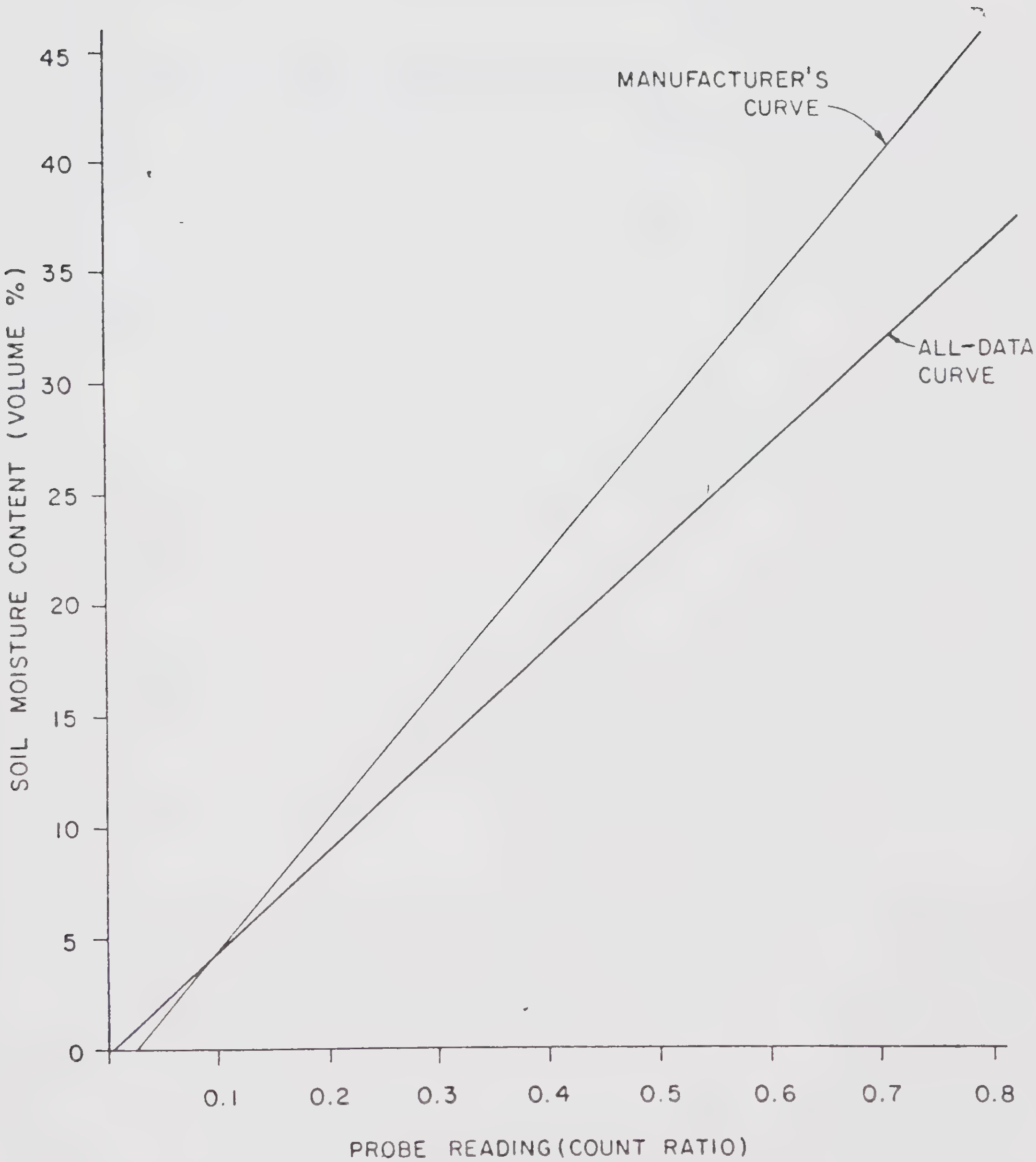


FIGURE: 8 ALL-DATA CALIBRATION CURVE COMPARED TO THE MANUFACTURER'S CURVE

soil minerals. Therefore, the all data calibration curve has removed the effects of the hydrogen contained in the soil minerals, making the two curves considerably different. For example, at a count ratio of 0.60 the manufacturer's curve gives a soil moisture content of 34% and the all data calibration curve gives a content of 27%.

5. Possible Sources of Error in Results

A number of precautions were taken to minimize error. All calibration curves were calculated using count ratio for the neutron probe measurement. This was done to remove the effect of the micro-processor unit built into the probe.

Bulk density samples were taken at all sites to calculate the soil moisture in volume percent. Duplicate soil samples were taken from each site at each depth. Each soil sampling site was approximately 1.0 to 1.5 m from the neutron probe access tube. The two soil sampling sites were normally on opposite sides of the access tube. The two samples at each depth were averaged to give a better indication of soil moisture around the access tube and to reduce variability.

Variability in soil moisture was evident in fields planted to row crops. Soil moisture was at times variable both between the rows and within the rows.

Soils in the area are heterogeneous and soil textures and water holding capacities are variable with vertical and lateral displacement. These last two factors and human errors in soil sampling exact depths probably were responsible for most of the variability in the calibration

curves.

B. Determination of Field Capacity Values

The determination of field capacity in an irrigation scheduling program is very important. The difference between field capacity and measured soil moisture is the irrigation requirement. Therefore, without an estimate of field capacity, an estimate of the irrigation requirement at any given time cannot be determined accurately.

There are three ways in which field capacity can be determined:

1. Direct field measurement.
2. Pressure plate method.
3. Using the percentage of sand and clay in an empirical equation.

All three methods were utilized; however, the direct field method was found to be the easiest and most reliable method. By measuring soil moisture after a saturating rain or irrigation, the field capacities are specific to each depth for each site in a field.

The other two methods of determining field capacity require soil sampling and laboratory analysis. Soil is a heterogeneous body and even in a very topographically uniform field, soil texture and water holding capacity can be quite variable with both vertical and lateral displacement. Table 7 shows field capacity values established with the neutron probe at five sites, and four depths at each site on a uniform 320 acre field.

Table 7 Field capacity values (mm/25cm) for five sites at four depths, on a uniform 320 acre field.

Depth in cm	Site No. 1	Site No. 2	Site No. 3	Site No. 4	Site No. 5	Maximum Variation
10 - 35 cm	78	76	73	73	86	13
35 - 60 cm	78	71	69	80	83	14
60 - 85 cm	78	72	76	77	84	12
85 - 110 cm	75	70	78	74	89	19
TOTAL	309	289	296	304	342	58

Table 7 shows the variation in soil water holding capacity, even on a uniform field. If soil samples are taken for laboratory analysis, the exact site soil sampled should be the same site used for the monitoring site for irrigation scheduling. If the same site is not used, then the estimated field capacity values could be seriously in error.

The primary problems with using laboratory data is that considerable time is required for analysis. Therefore, it is much easier and faster to estimate field capacity by taking direct readings in the field.

C. Frequency of Probe Readings

In scheduling irrigation, regular visits to each field are required to monitor soil moisture. One question that immediately arises is: "How frequently should soil moisture be measured?". The frequency of measurements is dependent on a number of factors:

1. type of crop, e.g. annual or perennial,

2. stage of crop growth,
3. the crop moisture use requirements,
4. the water holding capacity of the soil, and
5. the type of irrigation system used.

From the twenty-five sites monitored in 1981 with the neutron probe, five were monitored twice weekly, while all others were monitored once per week. Rain gauges were located at the five sites monitored twice per week. All five sites were located in a 320 acre corn field. Four of the five sites were irrigated by a towable pivot. The fifth site was in a corner of the field which did not receive irrigation.

From the twenty-five sites, seven sites were selected as being representative of soil moisture change and irrigation practices in Southern Alberta for 1981. Soil moisture profiles were plotted for the 10-35, 35-60, 60-85, and 85-110 cm zones as well as a plot for the total soil profile for each site. The seven sites are:

1. Non-irrigated corn field.

*2. Corn field irrigated with a towable pivot.

*3. Corn field irrigated with a towable pivot.

4. Alfalfa field irrigated with a wheelmove system.
5. Soft wheat field irrigated with a wheelmove system.
6. Sugar beet field irrigated with a wheelmove system.
7. Sugar beet field irrigated with a towable pivot.

*The same towable pivot was used to irrigate these two fields.

Both profiles are included to show the soil moisture differences

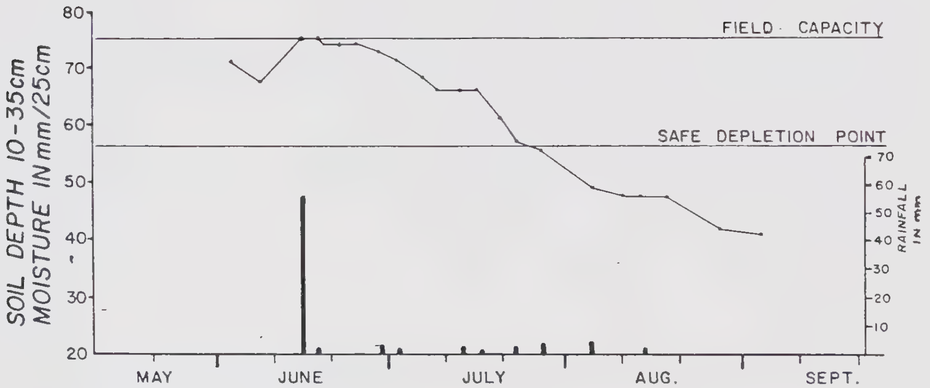
between the two fields.

The plotted soil moisture profiles are shown in Figures 9 to 15 respectively. The field capacity and allowable depletion levels are shown for each depth on each profile. Combined irrigation and precipitation values are included for Figures 9, 10, and 11.

There are two main types of irrigated crops: annual and perennial. The main difference between the two types of crops is that crop moisture use and therefore soil moisture withdrawal becomes very high early in the growing season for perennials. Annual crops use very little moisture early in the growing season and the amount of moisture gradually increases as the crop grows.

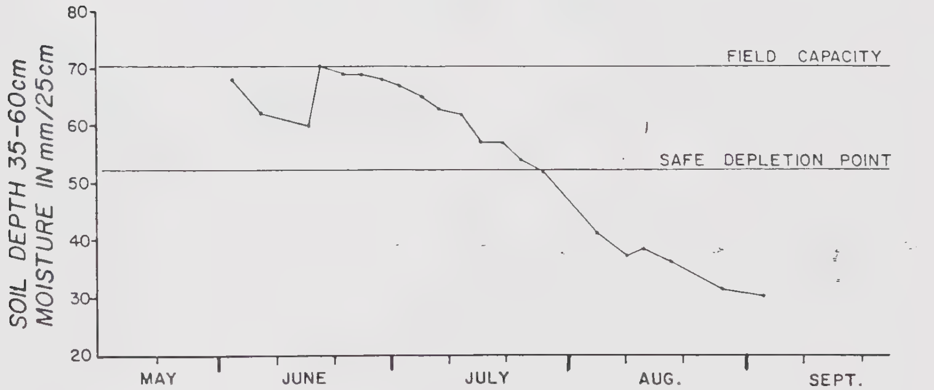
As a result, perennial crops need more frequent monitoring of soil moisture in the months of May and the first half of June than do annual crops. Figure 12 shows very dramatic soil moisture change in an alfalfa field in very early June. The first reading taken June 1, 1981 shows that soil moisture is above the allowable depletion level. The second reading, taken on June 8 just one week later, shows soil moisture at all depths to be below the allowable depletion level. This shows how quickly soil moisture status can change with a deep rooted crop.

Upon examination of all the other figures of annual crops of soil moisture change, none showed such dramatic changes of soil moisture in the month of June. Generally, soil moisture change for the annual crops in the month of June was slow, but gradually increased. There is a difference in the withdrawal of soil moisture



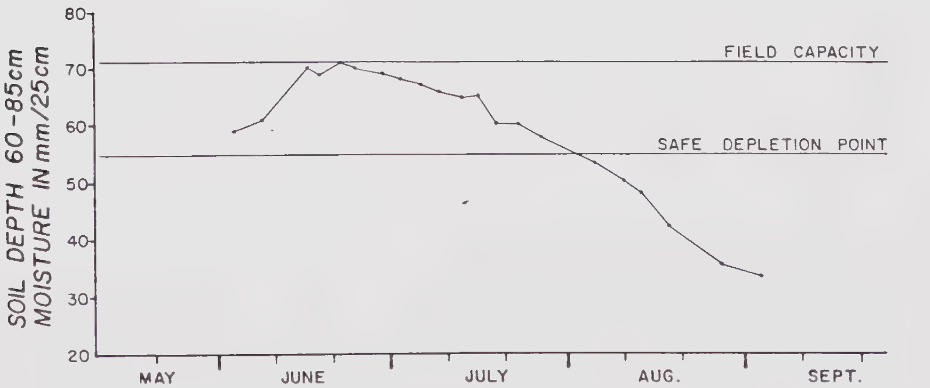
FULL LEVEL 76mm ALLOWABLE DEPLETION LEVEL 57mm

Figure 9(a) Soil moisture change in the 10-35cm zone



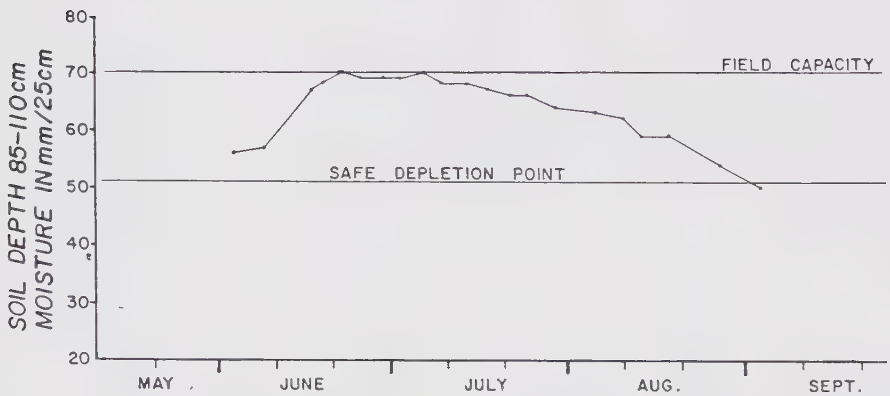
FULL LEVEL 71mm ALLOWABLE DEPLETION LEVEL 53mm

Figure 9(b) Soil moisture change in the 35 - 60cm zone



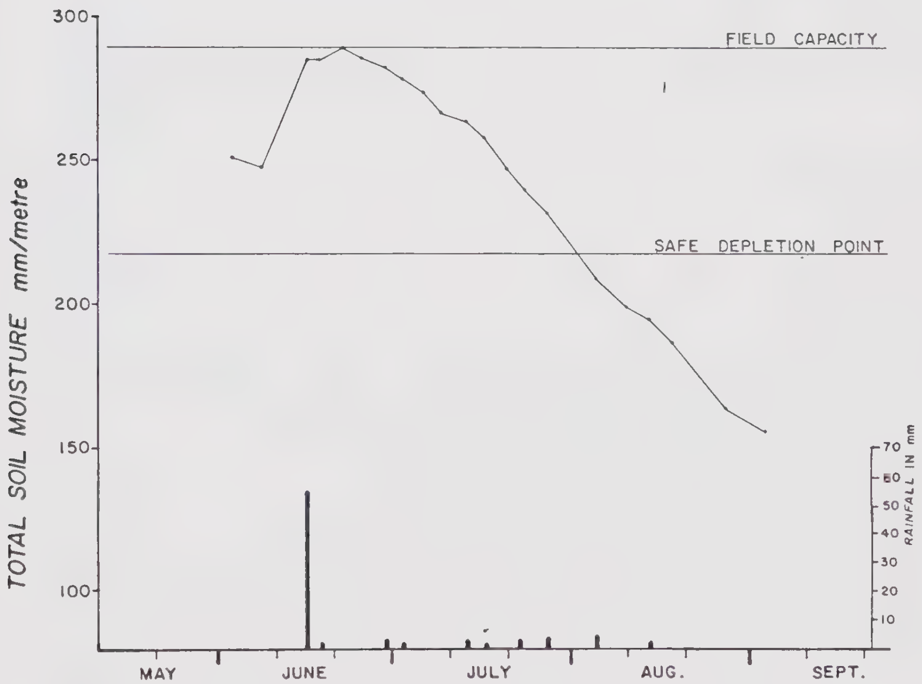
FULL LEVEL 72mm ALLOWABLE DEPLETION LEVEL 54mm

Figure 9(c) Soil moisture change in the 60-85cm zone



FULL LEVEL 70mm *ALLOWABLE DEPLETION LEVEL 51mm*

Figure 9(d) Soil moisture change in the 85-110cm zone

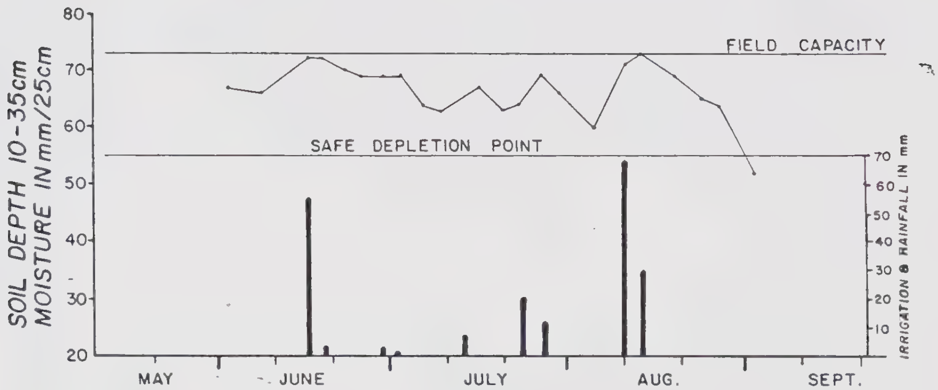


NAME: Freyman
FIELD: # 4 (not irrigated)
CROP: Corn

TOTAL AVAILABLE MOISTURE 289 mm
ALLOWABLE DEPLETION LEVEL 215mm
SOIL TEXTURE SCL to CL

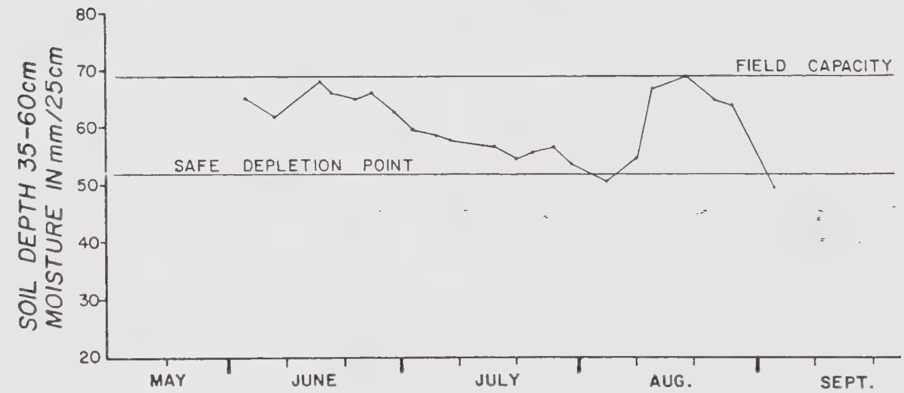
Figure 9(e) Soil moisture change in the total soil profile

Figure 9 Soil moisture change in a non-irrigated corner of a corn field.



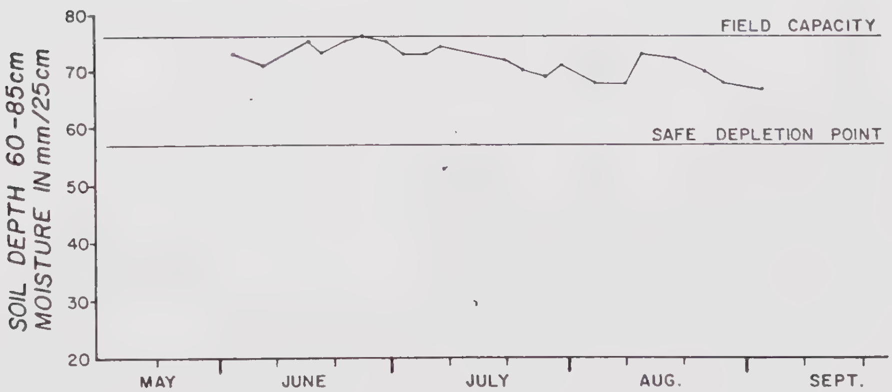
FULL LEVEL 73mm ALLOWABLE DEPLETION LEVEL 55mm

Figure 10(a) Soil moisture change in the 10-35cm zone



FULL LEVEL 69mm ALLOWABLE DEPLETION LEVEL 52mm

Figure 10(b) Soil moisture change in the 35 - 60cm zone



FULL LEVEL 76mm ALLOWABLE DEPLETION LEVEL 57mm

Figure 10(c) Soil moisture change in the 60-85cm zone

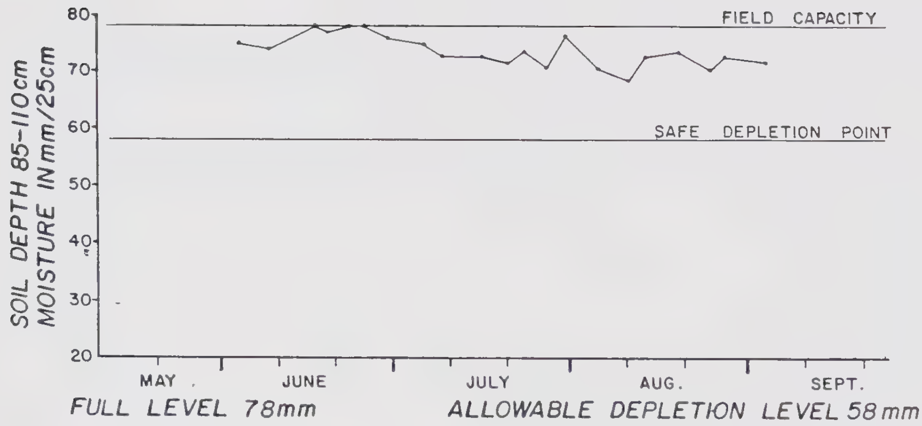


Figure 10(d) Soil moisture change in the 85-110cm zone

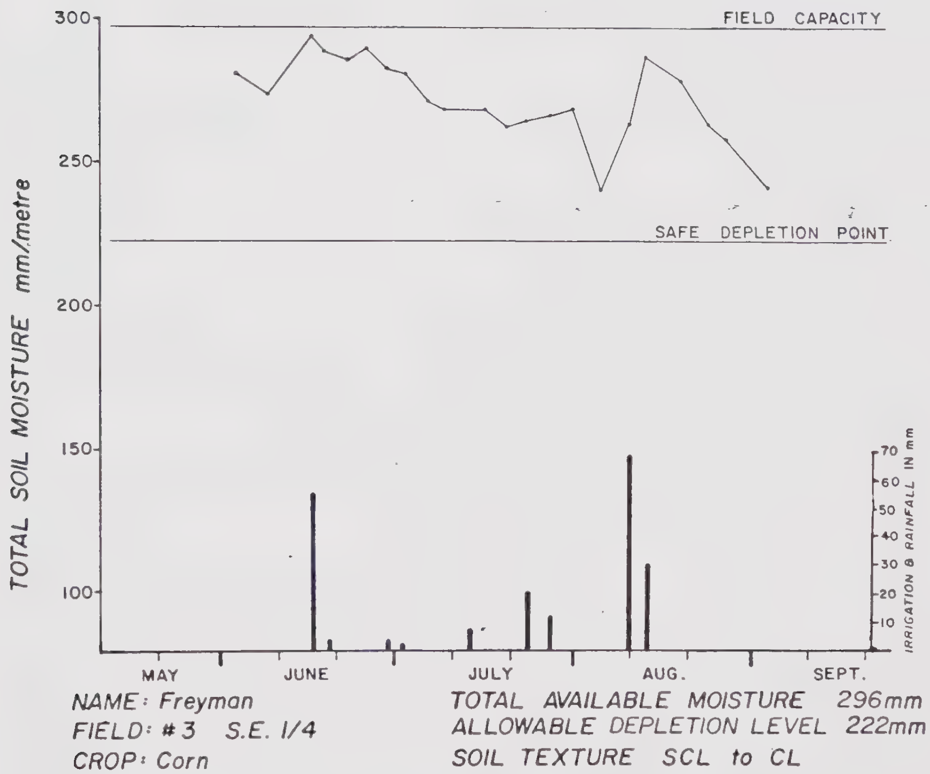
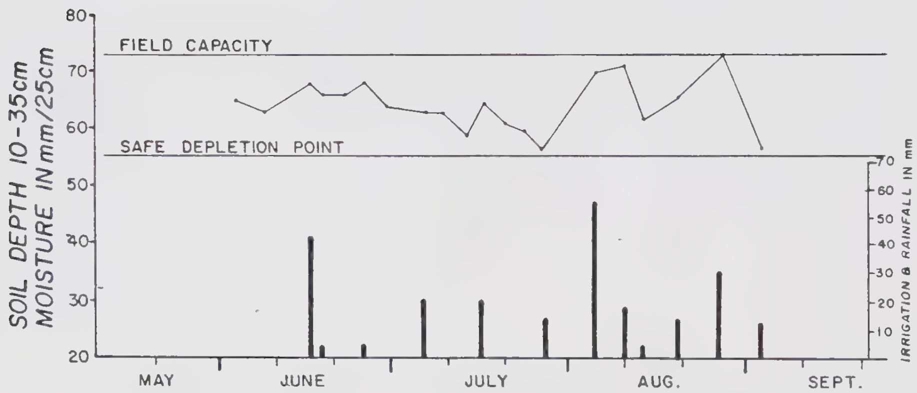


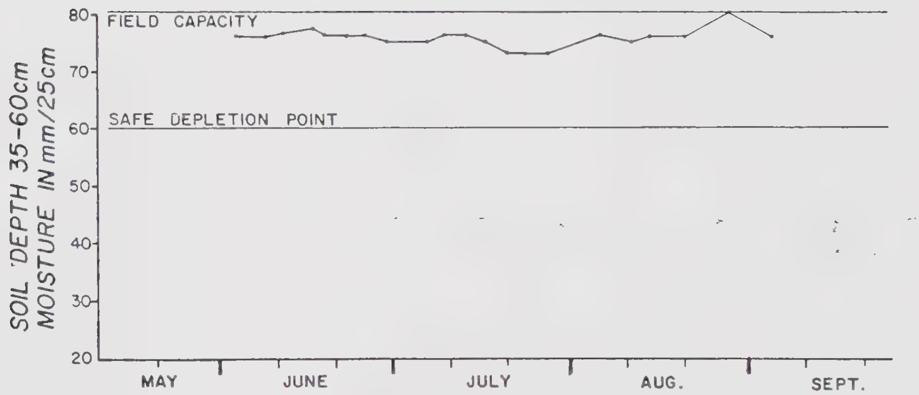
Figure 10(e) Soil moisture change in the total soil profile

Figure 10 Soil moisture change in a corn field irrigated with a towable pivot irrigation system.



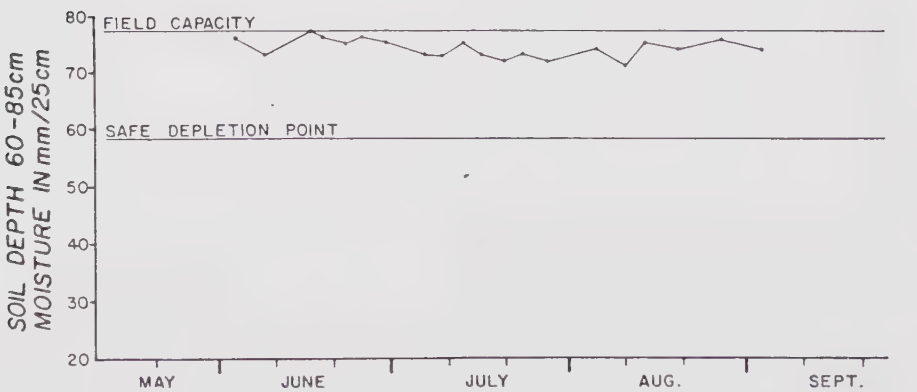
FULL LEVEL 73mm ALLOWABLE DEPLETION LEVEL 55mm

Figure 11(a) Soil moisture change in the 10-35cm zone



FULL LEVEL 80 mm ALLOWABLE DEPLETION LEVEL 60mm

Figure 11 (b) Soil moisture change in the 35 - 60cm zone



FULL LEVEL 77mm ALLOWABLE DEPLETION LEVEL 58 mm

Figure 11(c) Soil moisture change in the 60-85cm zone

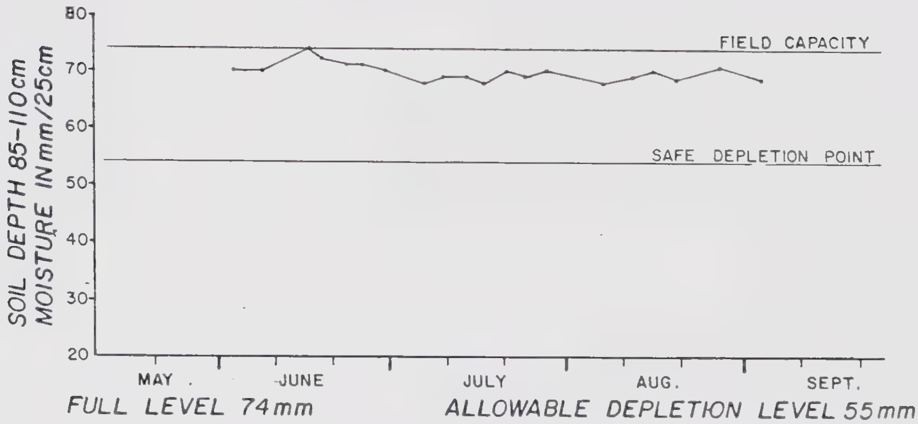


Figure 11(d) Soil moisture change in the 85-110cm zone

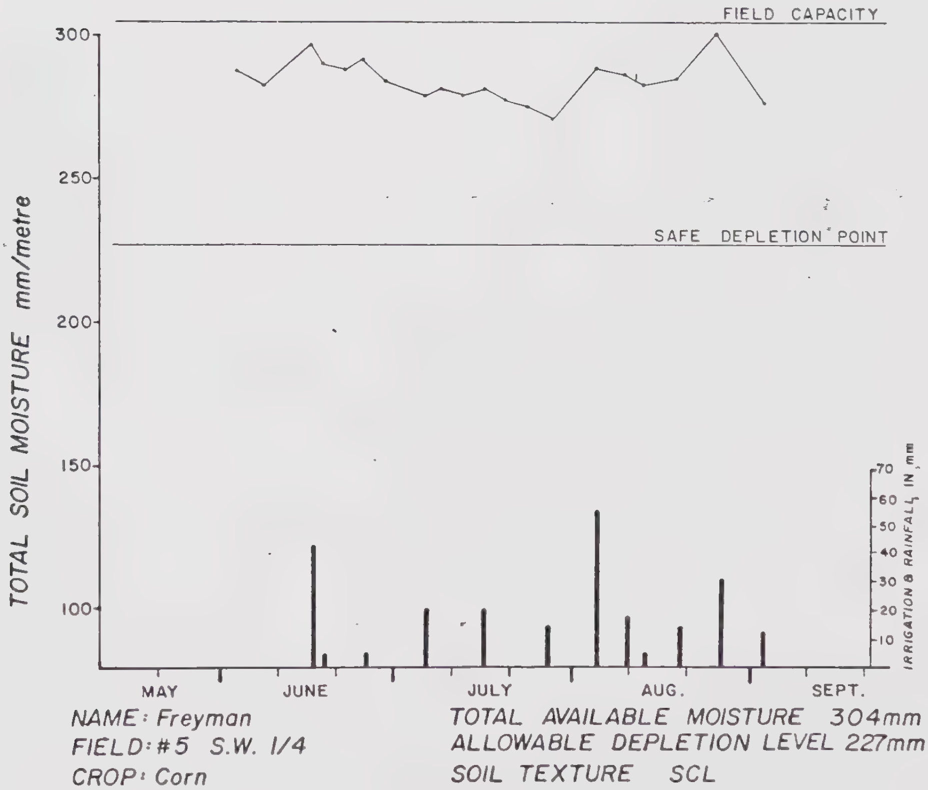


Figure 11 (e) Soil moisture change in the total soil profile

Figure 11 Soil moisture change in a corn field irrigated with a towable pivot.

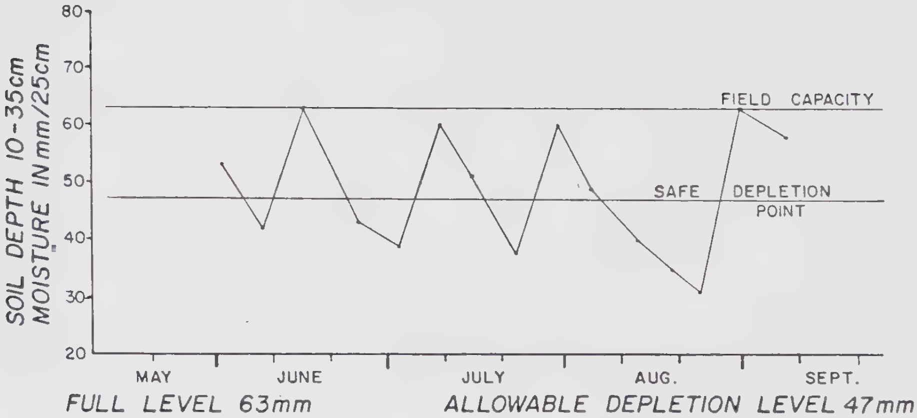


Figure 12(a) Soil moisture change in the 10-35cm zone

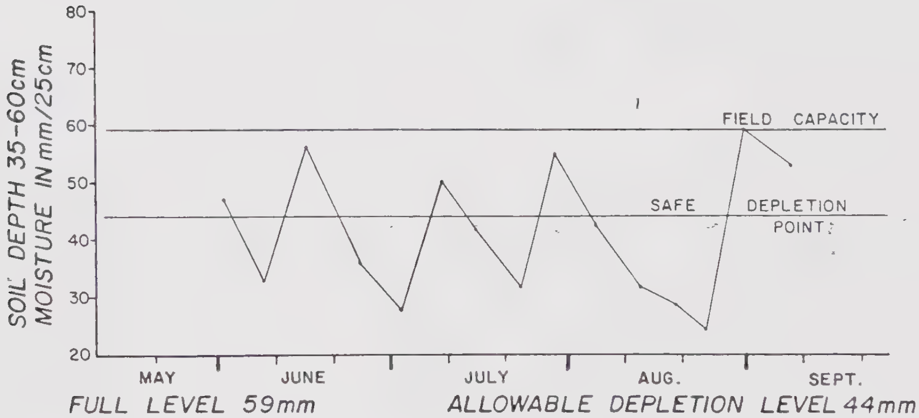


Figure 12(b) Soil moisture change in the 35 - 60cm zone

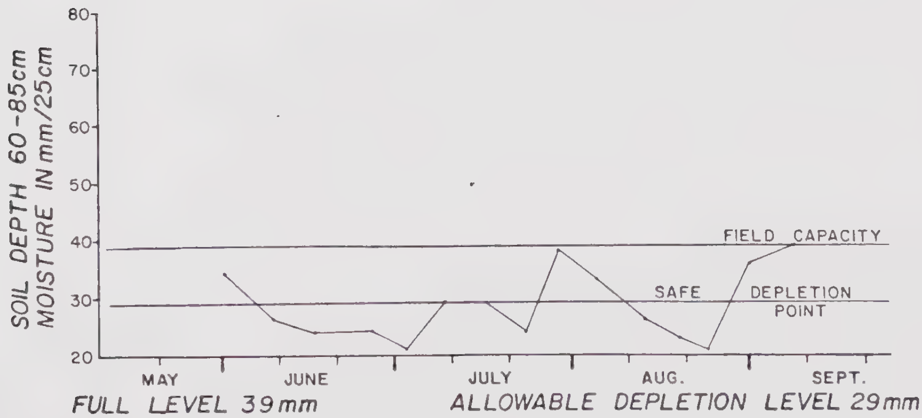
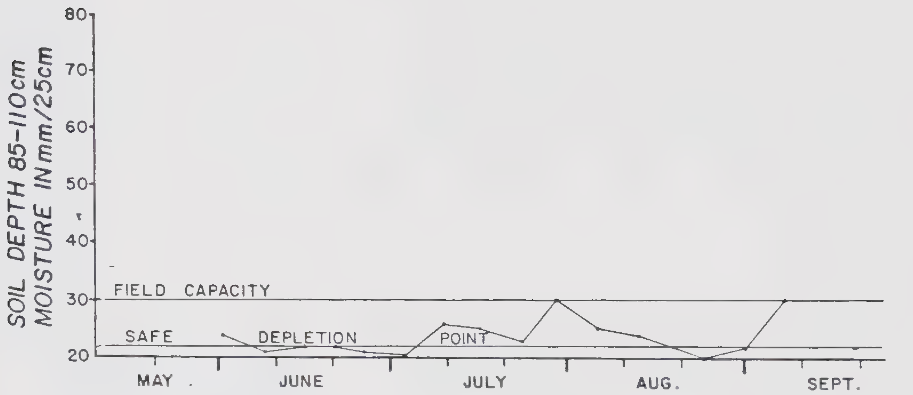
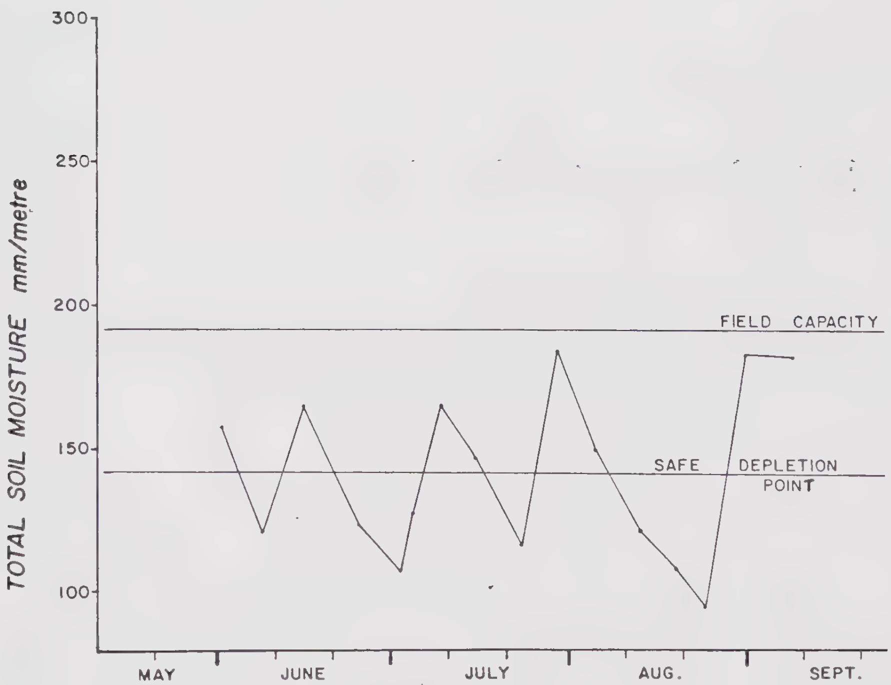


Figure 12(c) Soil moisture change in the 60-85cm zone



FULL LEVEL 30mm ALLOWABLE DEPLETION LEVEL 22mm

Figure 12(d) Soil moisture change in the 85-110cm zone

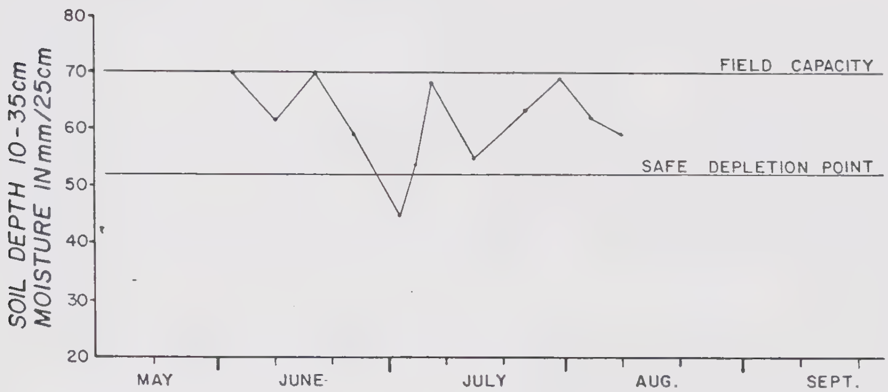


NAME: Machielse
FIELD: # 8
CROP: Alfalfa

TOTAL AVAILABLE MOISTURE 191mm
ALLOWABLE DEPLETION LEVEL 142mm
SOIL TEXTURE SL

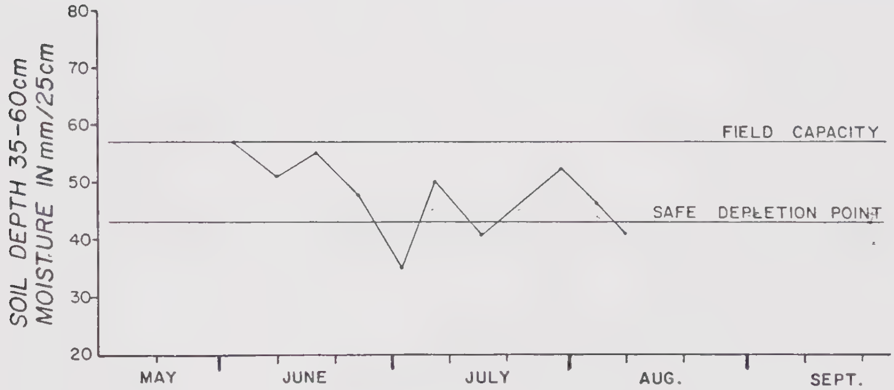
Figure 12(e) Soil moisture change in the total soil profile

Figure 12 Soil moisture change in an alfalfa field with a sandy loam soil and irrigated with a wheelmove sprinkler irrigation system.



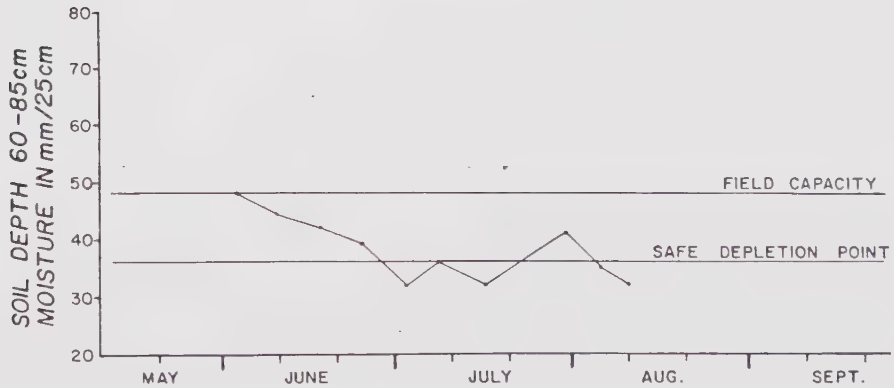
FULL LEVEL 70mm ALLOWABLE DEPLETION LEVEL 52mm

Figure 13(a) Soil moisture change in the 10-35cm zone



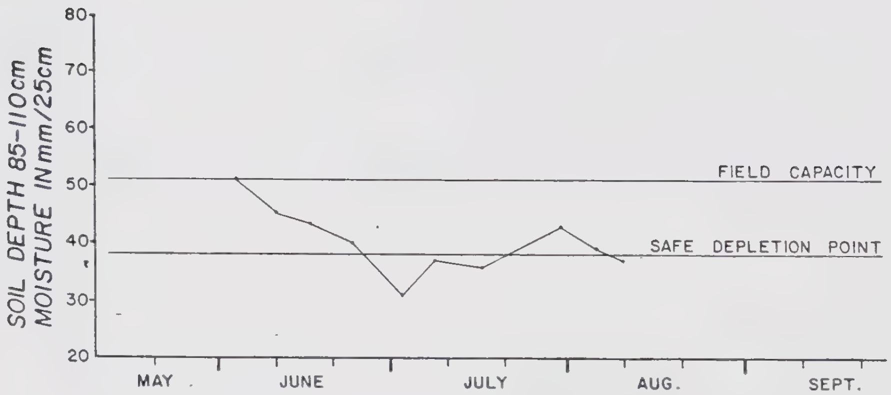
FULL LEVEL 57mm ALLOWABLE DEPLETION LEVEL 43mm

Figure 13(b) Soil moisture change in the 35-60cm zone



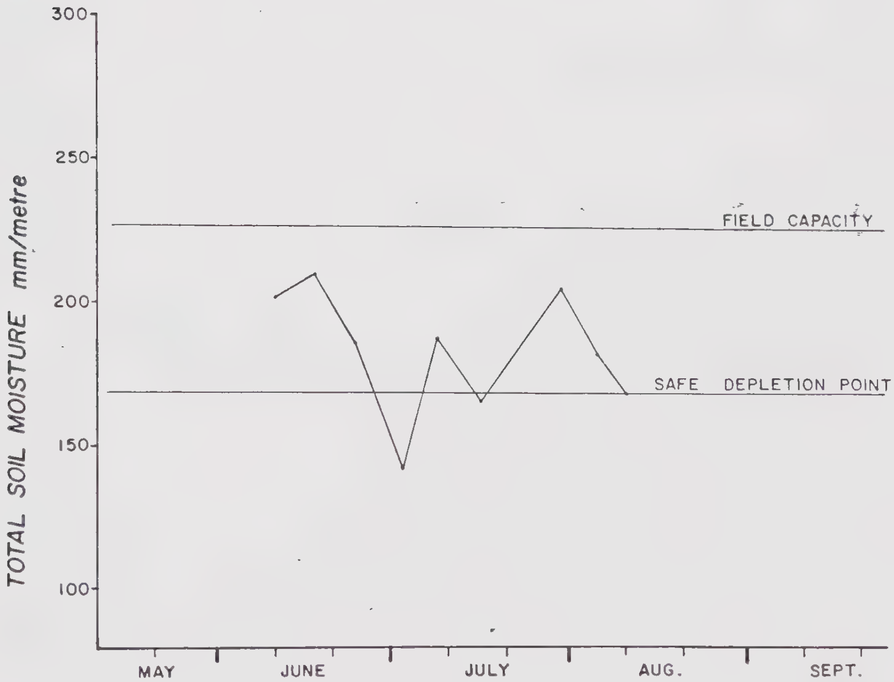
FULL LEVEL 48mm ALLOWABLE DEPLETION LEVEL 36mm

Figure 13(c) Soil moisture change in the 60-85cm zone



FULL LEVEL 51mm ALLOWABLE DEPLETION LEVEL 38mm

Figure 13(d) Soil moisture change in the 85–110cm zone



NAME: Uytdewilligen
FIELD: # 2
CROP: Soft wheat

TOTAL AVAILABLE MOISTURE 226mm
ALLOWABLE DEPLETION LEVEL 169mm
SOIL TEXTURE SCL – SL

Figure 13(e) Soil moisture change in the total soil profile

Figure 13 Soil moisture change in a soft wheat field irrigated with a wheelmove system.

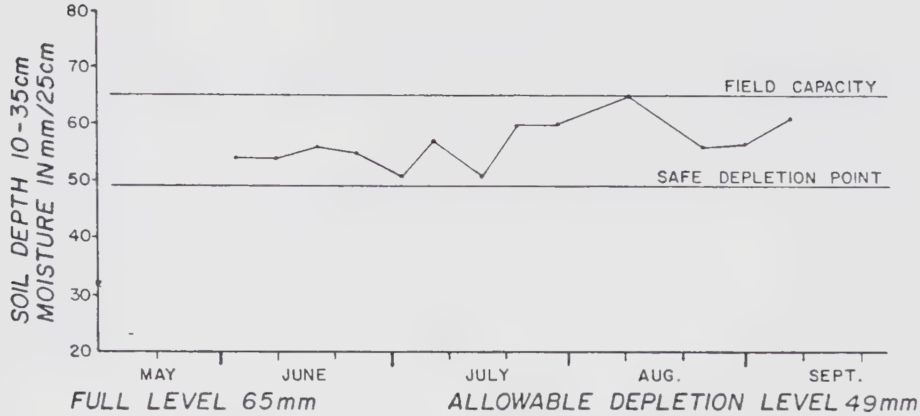


Figure 14(a) Soil moisture change in the 10-35cm zone

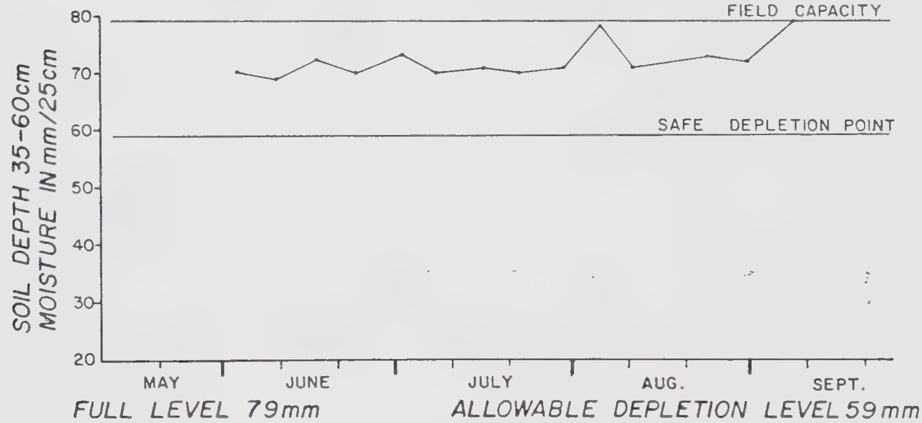


Figure 14(b) Soil moisture change in the 35 - 60cm zone

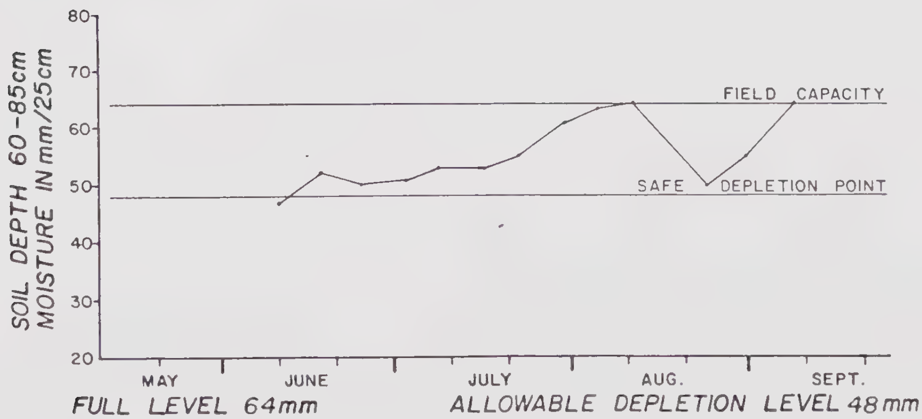


Figure 14(c) Soil moisture change in the 60-85cm zone

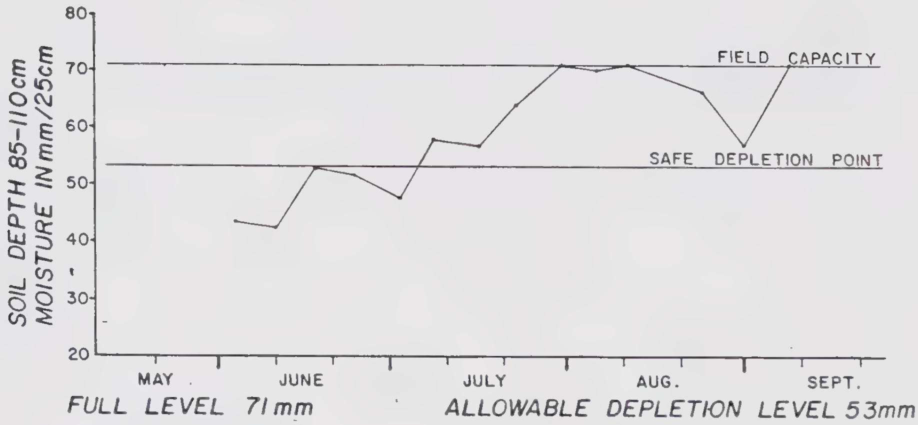


Figure 14(d) Soil moisture change in the 85-110cm zone

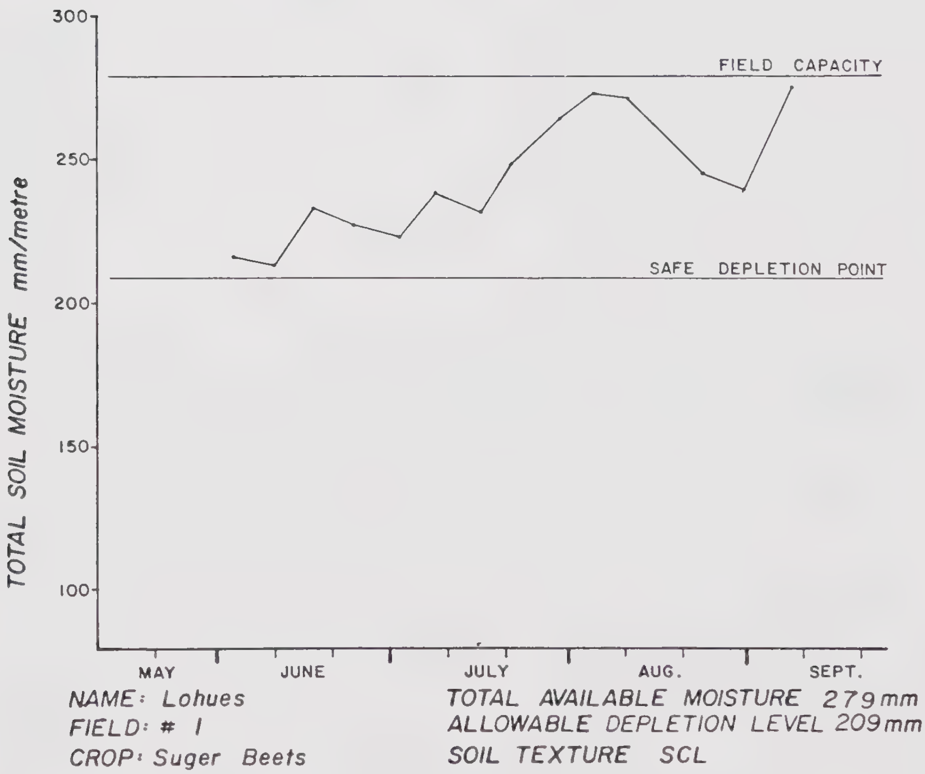
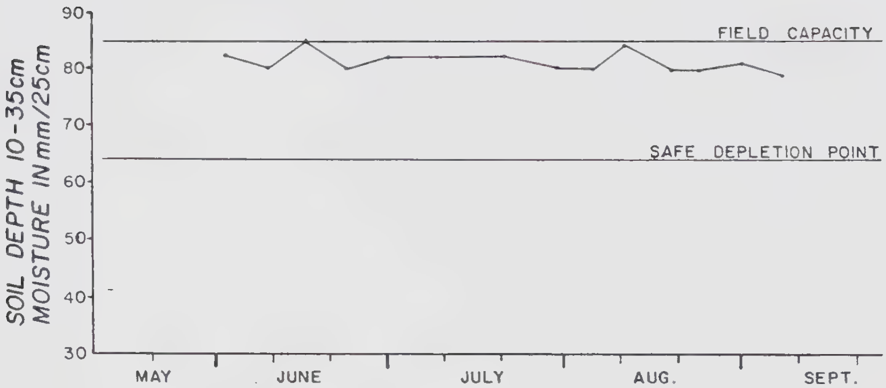


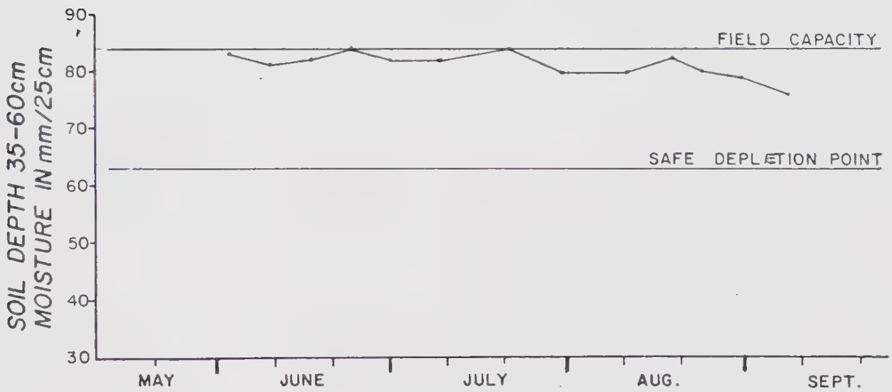
Figure 14(e) Soil moisture change in the total soil profile

Figure 14 Soil moisture change in a suger beet field with a wheel move irrigation system.



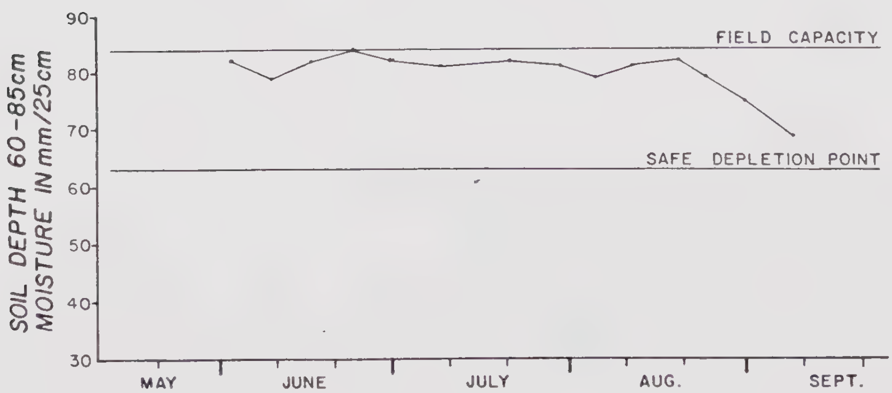
FULL LEVEL 85mm *ALLOWABLE DEPLETION LEVEL 64mm*

Figure 15(a) Soil moisture change in the 10–35cm zone



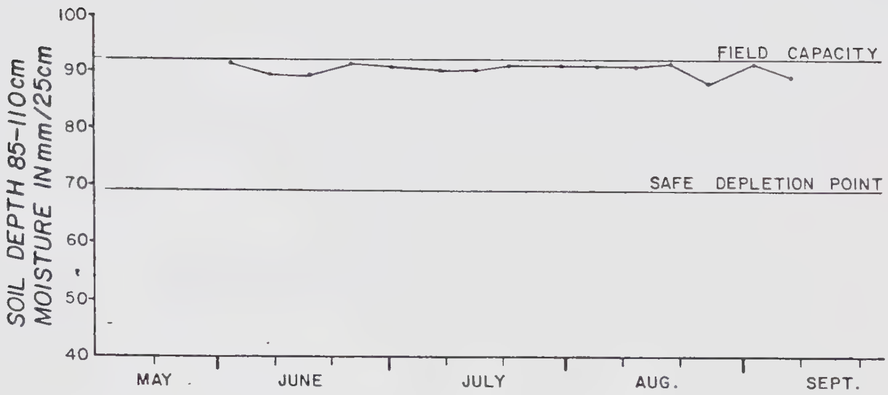
FULL LEVEL 84mm *ALLOWABLE DEPLETION LEVEL 63mm*

Figure 15(b) Soil moisture change in the 35 – 60cm zone



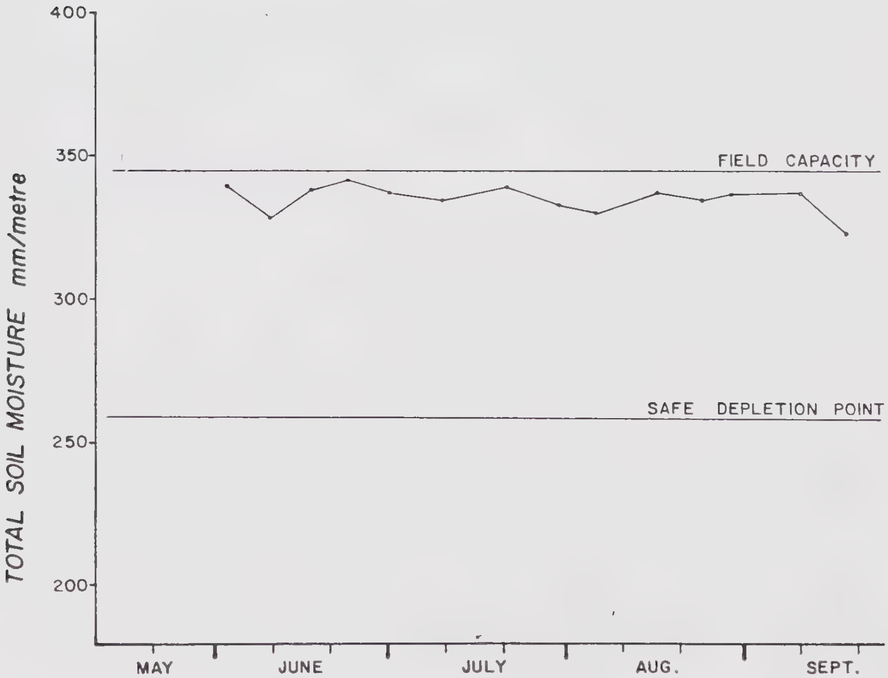
FULL LEVEL 84mm *ALLOWABLE DEPLETION LEVEL 63mm*

Figure 15(c) Soil moisture change in the 60–85cm zone



FULL LEVEL 92mm ALLOWABLE DEPLETION LEVEL 69mm

Figure 15 (a) Soil moisture change in the 85-110cm zone



NAME: Nemecek
FIELD: # 3
CROP: Sugar beet

TOTAL AVAILABLE MOISTURE 345mm
ALLOWABLE DEPLETION LEVEL 259mm
SOIL TEXTURE CL

Figure 15 (a) Soil moisture change in the total soil profile

Figure 15 Soil moisture change in a suger beet field irrigated with a pivot system.

between different types of annual crops. The row crops such as corn and sugar beets showed very gradual soil moisture change, whereas the grain crops such as soft wheat had increased soil moisture use, particularly in the latter half of the month of June. Figure 13 exhibits the increased rate of soil moisture withdrawal by soft wheat. Figures 10, 11, 14 and 15 show the very gradual rate of soil moisture change throughout the month of June.

In July, crop moisture use and soil moisture withdrawal is high for all crops. Therefore, all crops require very frequent monitoring of soil moisture in this month. In August, soil moisture use remains high for perennial and row crops, but most grain crops are ripening in early August and therefore monitoring of soil moisture can be suspended in early to mid August.

1. Crop Moisture Use

The two years of data were analyzed to estimate moisture use by various crops at different stages of growth. The average daily crop moisture use results are shown in Table 8.

The average results obtained compare favorably to those established over the years by the Agriculture Canada Research Station at Lethbridge. If, for example, a clay loam soil had a water holding capacity of 80mm/25 cm, the water holding capacity in a one metre profile would be 320 mm/m. The readily available moisture would be 80 mm/m. A crop such as alfalfa would take only 16 days to use the readily available soil moisture if the crop use rate was 5 mm/day.

Table 8 Average daily moisture use by various crops in millimetres.

* Values are not calculated as crops are normally harvested in August.

CROP / MONTH	ALFALFA	CORN	BARLEY	SOFT WHEAT	SUGAR BEETS
June	5.0	1.0	2.0	3.0	1.5
July	5.0	3.0	5.0	5.0	3.5
August	5.0	6.0	*	*	4.0
September	5.0	3.0	*	*	4.0

2. Measurement Under Different Irrigation Systems

There are two main types of sprinkler irrigation systems used by most irrigation farmers. One is the wheelmove system and the other is the pivot system. Both apply water to the soil through pressurized overhead pipe system. However, a wheelmove system remains stationary while irrigating and a pivot system is continually moving while irrigating. The result is that a 420 m pivot can apply 10 mm of water to 53 hectares of land in less than 24 hours. A wheelmove system is not capable of doing this. Normally a wheelmove system is moved twice or three times per day, and with an 18.5 m spacing between each set, it takes 14.5 to 21 days to irrigate 64 hectares, applying 100 to 150 mm of water.

Therefore, a pivot can be used to apply light frequent irrigations to a crop and a wheelmove system is used to apply larger amounts of water to a crop much less frequently. As a result of the differences in water application, the change of soil moisture under each type of system is quite different. Figures 10, 11 and 15 show soil moisture change under pivot systems. Figures 12, 13 and 14 show soil moisture change under wheelmove systems. Figure 9 shows soil moisture change if no irrigation water is applied. With different irrigation management practices, the need for different frequencies of soil moisture measurement must be determined.

When soil moisture is near field capacity and a pivot system is the method of irrigation, a field technician could estimate soil moisture depletion by the crop to determine when soil moisture

would approach the allowable depletion level. Then the technician could come back at that time to check soil moisture levels. This is good in theory; however, an irrigation farmer would not want to let his pivot sit idle for several weeks and let the soil moisture approach the allowable depletion level. Instead, the irrigator would want to take full advantage of the ability of the pivot to apply light, frequent amounts of water to maintain soil moisture at a reasonably high level. This factor would become much more critical if the same pivot is used to irrigate two quarter sections of land. Based on soil moisture levels, an irrigator must make decisions on when to irrigate each field, how much total water to apply and when the pivot should be manually towed to the other quarter section. Therefore, under a pivot system, frequent monitoring of soil moisture is required to enable the irrigator to maintain soil moisture near field capacity, and assist the farmer in making management decisions on the need for moving irrigation equipment.

Under a wheelmove system when the soil is at field capacity, again a technician could estimate soil moisture use by the crop to determine when soil moisture would approach the allowable depletion level. Later a technician could come back and recheck soil moisture. This would be a more acceptable procedure with a field irrigated with a wheelmove system; however, it may not give the irrigator all the information and peace of mind he requires to make his irrigation management decisions. Instead, the irrigator wants to know exactly what his soil moisture status is on a regular basis, to enable him to determine exactly when to schedule his irrigation system to be back to the location in

the field where soil moisture is monitored, before the moisture level reaches the allowable depletion level.

Although methods of irrigation vary, irrigation farmers on an irrigation scheduling program require soil moisture status information on a regular basis in order to plan their overall farm irrigation management program from week to week.

D. Number of Neutron Probe Readings Required per Profile

The number of probe readings required at a given site to determine accurately the soil moisture content is another important question facing irrigation schedulers. In an attempt to answer it, probe readings were taken at 12.5 cm and 25 cm intervals at five different sites to a depth of 1.0 metre. The depths of measurement for the 12.5 cm depth interval were 25.0, 37.5, 50.0, 62.5, 75.0, 87.5 and 100.0 cm.

A total of 23 sets of readings were taken at the five sites during the summer of 1981. Soil moisture content was then determined for 0 to 100 cm depth, 0 to 50 cm depth and 50 to 100 cm depth for both the 12.5 cm and 25 cm interval readings. Soil moisture was calculated in both volume percent and in millimetres. Table 9 shows the results of the two different intervals of readings.

Visual inspection of the data in Table 9 shows that very little difference exists in the total millimetres of moisture between the 12.5 and 25 cm increment readings. The greatest difference between the 0 - 100 cm depths was only 3.0 mm (1.3%) and occurred

Table 9 Soil moisture results in millimetres using 12.5 and 25 cm increment readings with a neutron probe.

INTERVALS		12.5 cm INTERVAL			25 CM INTERVAL		
Date	Site	0-100	0-50	50-100	0-100	0-50	50-100
81 07 23	3	251	120	131	251	117	135
81 07 30	3	253	120	133	251	118	133
81 08 05	3	239	111	128	238	109	129
81 08 13	3	263	131	132	265	128	137
81 08 27	3	235	112	123	237	111	126
81 09 03	3	217	98	119	219	95	124
81 07 23	4	230	109	121	230	108	122
81 08 05	4	198	91	107	200	92	108
81 08 13	4	182	87	95	182	85	97
81 08 27	4	157	77	80	155	75	80
81 09 03	4	149	75	74	150	74	76
81 07 23	2	278	133	145	276	133	143
81 08 13	2	266	126	140	264	125	139
81 07 23	5	264	122	142	262	119	143
81 08 05	5	279	135	144	278	133	144
81 08 13	5	264	122	142	261	119	142
81 08 27	5	280	134	146	279	134	145
81 09 03	5	257	116	141	254	113	141
81 07 23	6	314	150	164	314	150	164
81 08 05	6	310	149	161	309	148	162
81 08 13	6	305	145	160	304	144	160
81 08 27	6	309	148	161	311	148	163
81 09 03	6	304	143	161	304	143	161

at site #5 on 81 08 13 and 81 09 03; between the 0 - 50 cm depths was 3.0 mm (1.3%) at several sites; and between the 50 - 100 cm depths was 5.0 mm (2.4%) at site #3 on 81 09 03.

There is a definite trend for the 12.5 cm increment readings to have slightly higher moisture contents for the 0 - 50 cm depth interval and slightly lower ones for the 50 - 100 cm depth when compared to the 25.0 cm increment readings. The differences between the two-increment readings is very small however. The difference of 3.0 mm (1.3%) as the greatest difference between the 0 - 100 cm depths is insignificant when measuring moisture for the purpose of irrigation scheduling. Even the differences of 3.0 mm (1.3%) and 5.0 (2.4%) for the 0 to 50 and 50 to 100 cm depths are rather small.

Linear regression analysis was used to compare the data from the two different increment readings. Table 9 shows the linear regression formula, standard error of estimate and the correlation coefficient for the 0 - 100 cm, 0 - 50, and 50 - 100 cm depths, comparing four readings with seven readings at a site with the neutron probe. The x represents the 12.5 cm increment and y represents the 25.0 cm increment readings.

The information in Table 10 shows that there is very good correlation of results when comparing the results of four readings and seven readings at one site with the neutron probe.

To compare further the results of four readings to seven readings per site, results of three separate sets of readings were plotted in the form of bar graphs, and are shown in Figures 16, 17,

Table 10 Comparison of data using two depth increments of probe readings.

The table shows the linear regression formula, standard error of estimate and correlation coefficient for the 0 - 100 cm, 0 - 50 cm and 50 - 100 cm depths.

DEPTH	FORMULA	STANDARD ERROR OF ESTIMATE	CORRELATION COEFFICIENT (r^2)
0 - 100 cm	Y=1.48 + (x) 0.993	1.69	0.999
0 - 50 cm	Y=2.86 + (x) 1.012	1.17	0.998
50 - 100 cm	Y=4.46 + (x) 0.975	1.81	0.995

and 18, and represent site #6 81 09 02, site #3 81 08 13, and site #5 81 09 03 respectively.

The bar graphs graphically show the location in a soil profile where the soil moisture content is either over or underestimated when using 25 cm increment readings as compared to the 12.5 cm increment readings. The 0-12.5 cm moisture level was arbitrarily taken at 3/4 of the 25 cm reading.

The three major areas where the soil moisture estimations vary occur between 31.0 and 42.5 cm, between 57.0 and 69.5 cm and between 81.0 and 93.5 cm.

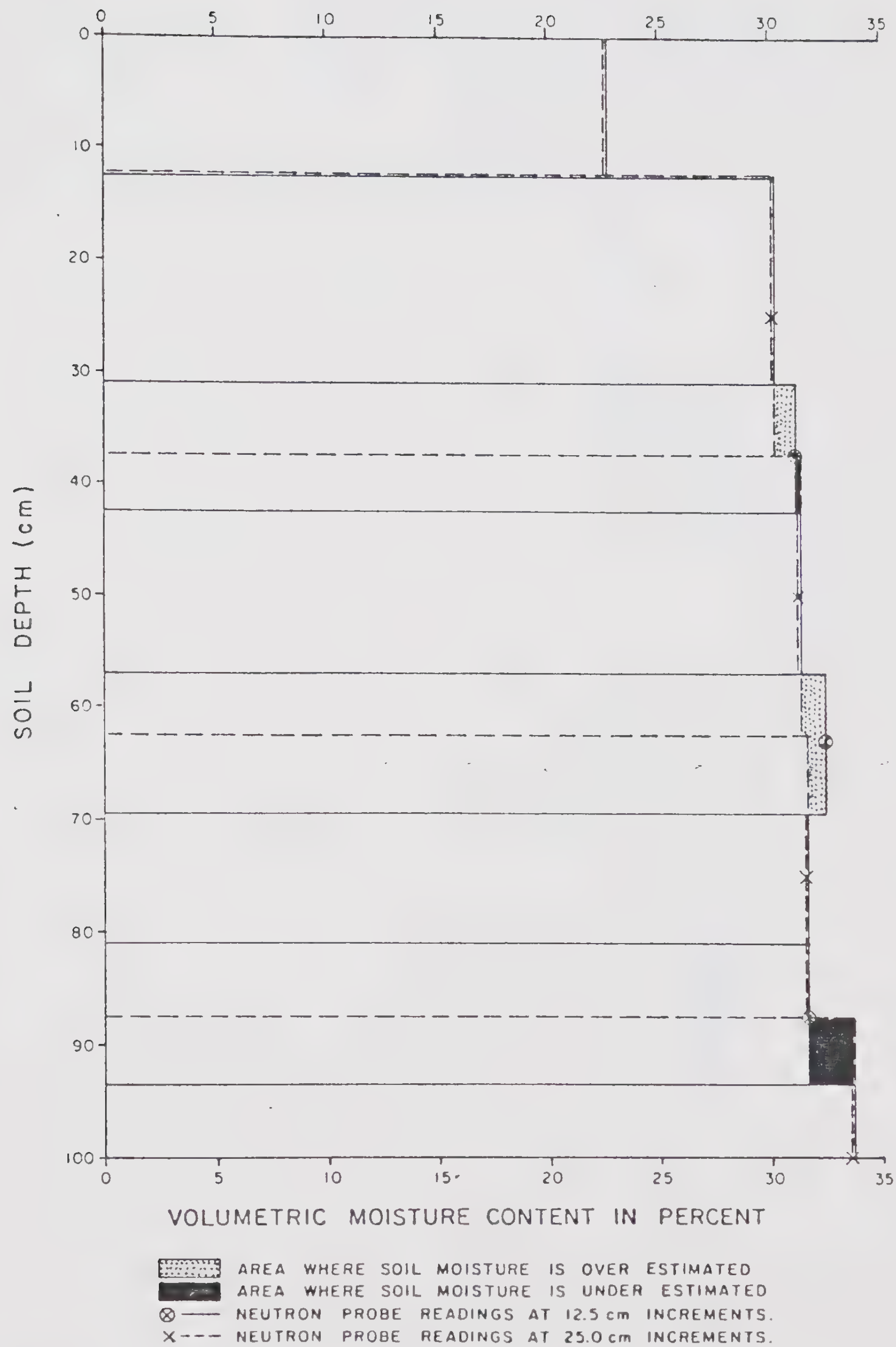


FIGURE 16 BAR GRAPH SHOWING MAXIMUM SOIL MOISTURE VARIATION BETWEEN 4 AND 7 READINGS PER SITE

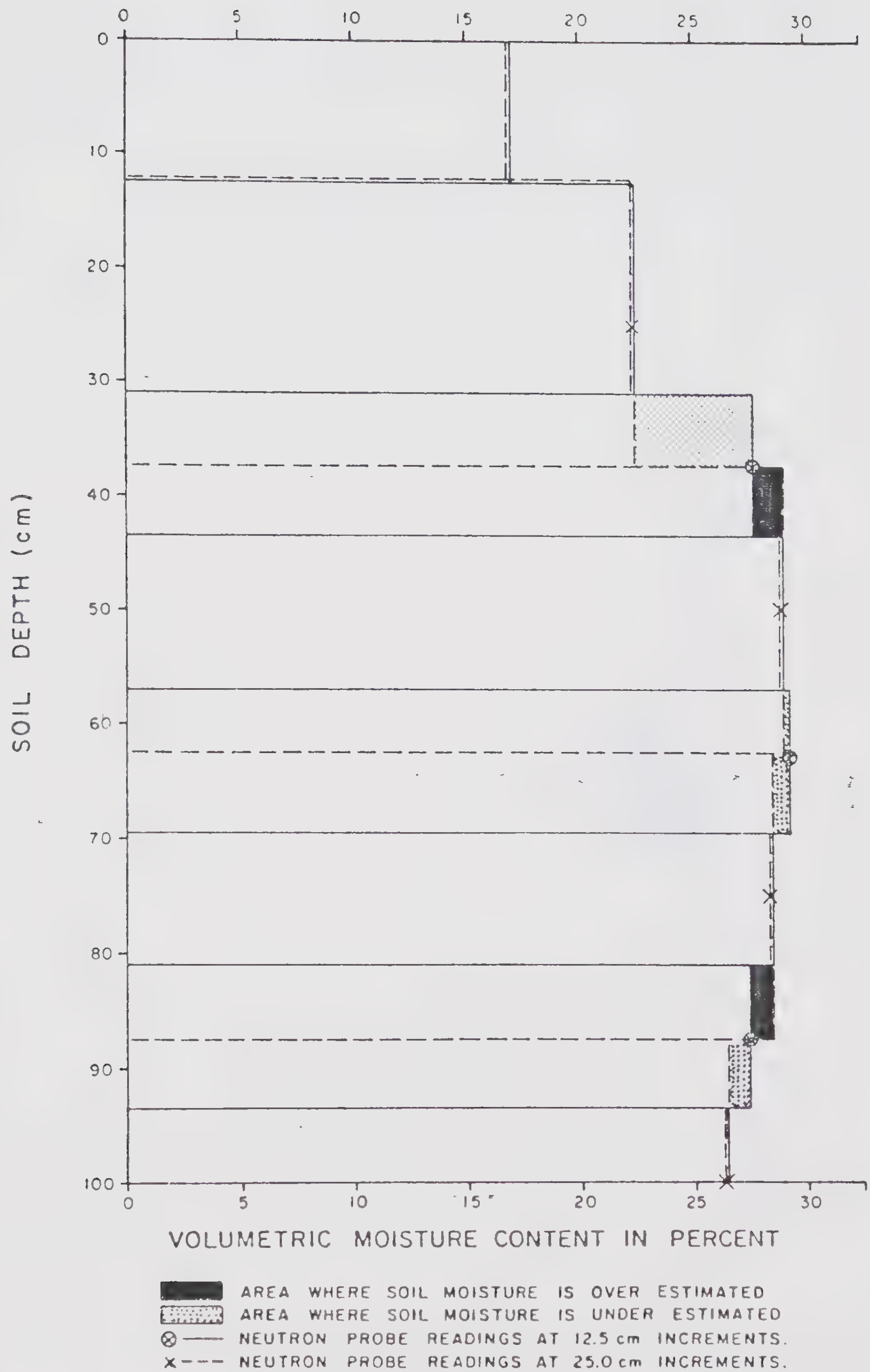


FIGURE 17 BAR GRAPH SHOWING MAXIMUM SOIL MOISTURE VARIATION BETWEEN 4 AND 7 READINGS PER SITE

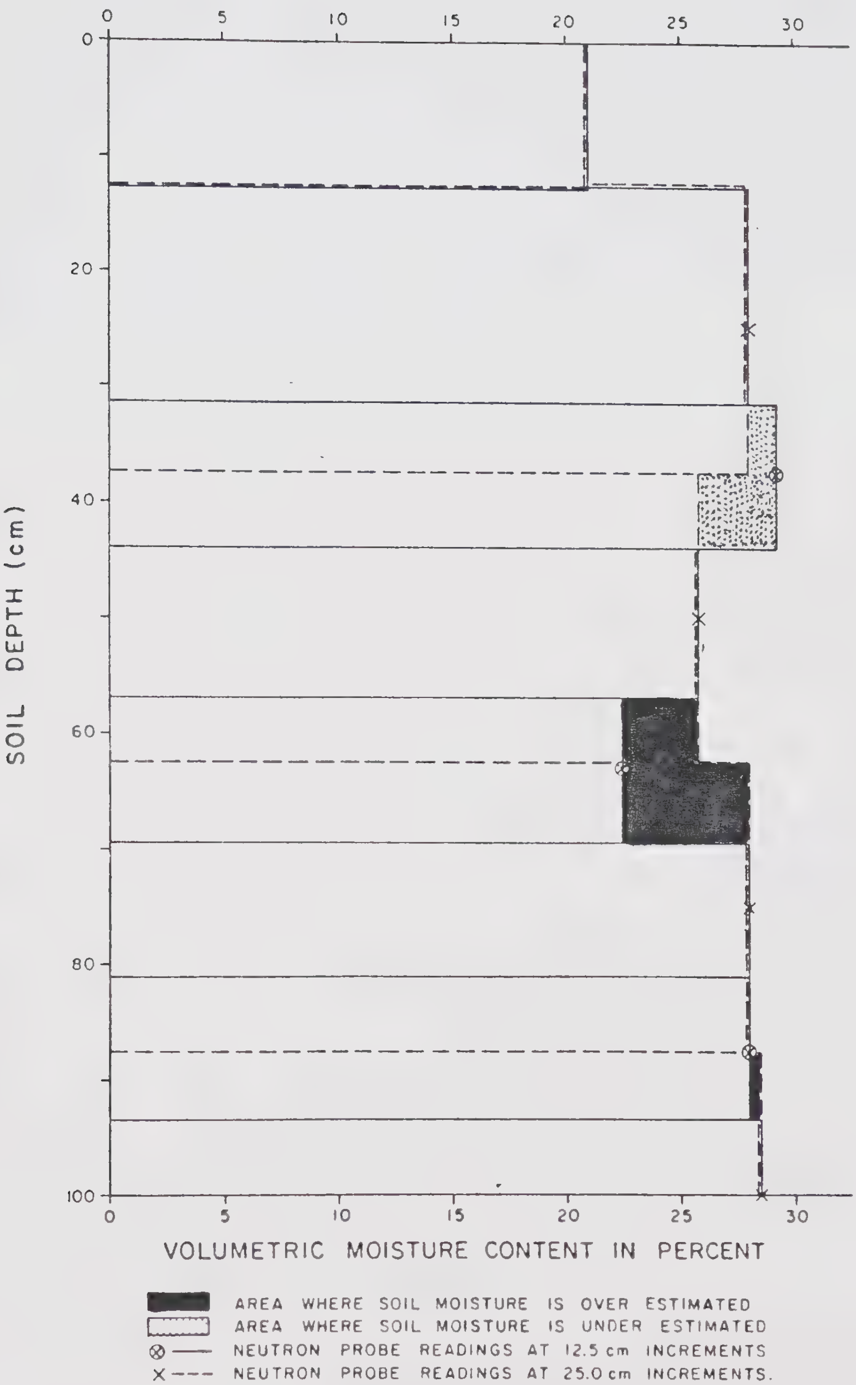


FIGURE: 18 BAR GRAPH SHOWING MAXIMUM SOIL MOISTURE VARIATION BETWEEN 4 AND 7 READINGS PER SITE

V. CONCLUSIONS

A. Neutron Probe Calibration

Results indicate that there is no significant effect of soil texture on neutron probe calibration. Bulk density does have an effect on neutron probe calibration; however, for the purpose of scheduling irrigation this effect can be ignored. The all data calibration curve was found to be satisfactory for irrigation scheduling in the Lethbridge area.

B. Number of Neutron Readings Required per Profile

The analysis of the data shows there is exceptionally good agreement of total profile soil moisture with the neutron probe using four readings as compared to using seven readings in a 100 cm soil profile. The results show that in a 100 cm soil profile, the total moisture difference between four and seven readings was never greater than 1.3%, a rather insignificant amount. Thus, taking soil moisture readings at 25 cm increment intervals provides comparible results to taking readings at 12.5 intervals. Taking readings in moist soil conditions at increments greater than 25 cm will result in a radius of measurement which does not overlap.

Therefore, it appears that a 25 cm depth interval provides sufficiently accurate measurements of total profile soil water for the purpose of irrigation scheduling.

C. Frequency of Probe Readings

The frequency of soil moisture measurement can be based on a number of factors, which include the rate that the crop is using

moisture and the type of irrigation system being utilized.

For perennial crops, regular readings of once per week throughout the growing season are required. For annual crops, less frequent readings of once every two weeks are satisfactory until the crop enters a moderate to high moisture use rate. Then more frequent readings of once per week are required, until the crop begins to ripen or nears the harvest date. The primary reason for a regular field check is to provide the farmer with the information required to plan the overall farm irrigation management program for the next one to two weeks.

Based on these observations, three conclusions can be drawn regarding the frequency of measurement of soil moisture for the purpose of irrigation scheduling:

1. Perennial crops such as alfalfa and pasture should be monitored at least once per week during the growing season, beginning as soon as possible at the start of the growing season and continuing until at least mid September.
2. Annual crops such as most grains require only periodic soil moisture measurement early in the growing season. Once every two weeks in May and the first half of June should be sufficient; however, for the remainder of the season, soil moisture withdrawal is great enough to warrant reading once per week.
3. Annual crops such as corn and sugar beets require only periodic measurement in the months of May and June. In the months of July and August, soil moisture readings once per week are required due to increased soil moisture withdrawal.

For long growing season crops such as sugar beets, several readings in September are also required.

4. The frequency of readings could actually be reduced if the irrigation scheduling technician simply did not return until a few days before the soil moisture reached the safe depletion point. The number of days of available moisture remaining can be calculated from information on the Irrigation Scheduling Card. The number of days is determined by dividing the present crop moisture use into the remaining available soil moisture. This approach has advantages and disadvantages. The disadvantage is that the optimum time between readings would be reduced and second, the irrigation scheduling technician would not be able to cover the same route on a regular basis. The advantage is that a greater number of fields could be monitored by a single technician.

VI. SUMMARY

Considerable research and development has been undertaken in the area of irrigation scheduling over the years. One tool, the neutron probe, has only recently been used for the purpose of on-farm irrigation scheduling. Results of this study show that the neutron probe can be utilized to provide quick, accurate, and reliable soil moisture measurements for irrigation scheduling.

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